STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS

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DIVISION OF WATER RESOURCES
EDWARD HYATT, State Engineer

Reports on State Water Plan Prepared Pursuant to Chapter 832, Statutes of 1929

BULLETIN No. 33

RAINFALL PENETRATION AND CONSUMPTIVE USE OF WATER

IN SANTA ANA RIVER VALLEY AND COASTAL PLAIN

A Cooperative Progress Report by the Division of Agricultural Engineering of the U. S. Department of Agriculture.

1930

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TABLE OF CONTENTS

Chapter IV

Chapter V

Chapter VI

Part II

EVAPORATION AND TRANSPIRATION LOSSES FROM MOIST AREAS

Chapter I

Chapter II

Chapter III

Appendix

LIST OF TABLES

Part I

Part II

Appendix

LIST OF PLATES

Part I

Part II

LETTER OF TRANSMITTAL

Mr. Edward Hyatt,
State Engineer,
Sacramento, California.

Dear Sir: There is transmitted herewith a cooperative progress report on "Rainfall Penetration and Consumptive Use of Water in Santa Ana River Valley and Coastal Plain" (in reference to irrigation).

This report contains a description of the methods used, plan followed, and data obtained from the investigations conducted under cooperative contract in the Santa Ana River area, dealing with (1) penetration of rain falling upon the valley floor, and consumptive use of water by crop and native plants; and (2) loss of water from moist areas.

The report indicates the extent to which rain falling upon the valley floor may penetrate below the reach of plant roots and ultimately supplement the ground water supply. There is indicated, also, the relation of rainfall to irrigation requirements and the amount of water lost through transpiration and direct evaporation in moist areas.

Respectfully submitted,

W. W. McLaughlin

Associate Chief,
Division of Agricultural Engineering,
U. S. Department of Agriculture.

Berkeley, California,
November 1, 1930.

ACKNOWLEDGMENT

The research studies set forth in this bulletin were planned jointly by the cooperating agencies with advice of officials of Orange, Riverside and San Bernardino counties. Paul Bailey, A. L. Sonderegger, G. S. Hinckley and W. P. Rowe, Board of Consulting Engineers for southern California, furnished valuable advice during the progress of the work. The Board of Water Commissioners of the City of San Bernardino and William Starke, Superintendent of the San Bernardino Municipal Water Department, provided the Devil Canyon shaft and the site for the San Bernardino Experiment Station. Acknowledgment also is made of the courtesies extended by F. C. Ebert, H. C. Troxell, and Jarrett Oliver of the U. S. Geological Survey. O. V. P. Stout of the Division of Agricultural Engineering, furnished data relative to the Mariotte Tank.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

DIVISION OF AGRICULTURAL ENGINEERING

Cooperating in

Water Resources Investigation

W. W. McLaughlin ------------------------------- *Associate Chief*

This bulletin was prepared by

Harry F. Blaney, *Irrigation Engineer,*

C. A. Taylor, *Assistant Irrigation Engineer,*

and

A. A. Young, *Assistant Irrigation Engineer.*

CHAPTER 832, STATUTES OF 1929

An act making an appropriation for work of exploration, investigation and preliminary plans in furtherance of a coordinated plan for the conservation, development, and utilization of the water resources of California including the Santa Ana river, Mojave river and all water resources of southern California.

[I object to the item of $450,000.00 in section 1 and reduce the amount to $390,-000.00. With this reduction I approve the bill. Dated June 17, 1920. C. C. YOUNG, Governor.]

The people of the State of California do enact as follows:

SECTION 1. Out of any money in the state treasury not otherwise appropriated, the sum of four hundred fifty thousand dollars, or so much thereof as may be necessary, is hereby appropriated to be expended by the state department of public works in accordance with law in conducting work of exploration, investigation and preliminary plans in furtherance of a coordinated plan for the conservation, development and utilization of the water resources of California including the Santa Ana river and its tributaries, the Mojave river and its tributaries, and all other water resources of southern California.

SEC. 2. The department of public works, subject to the other provisions of this act, is empowered to expend any portion of the appropriation herein provided for the purposes of this act, in cooperation with the government of the United States of America or in coperation with political subdivisions of the State of California; and for the purpose of such cooperation is hereby authorized to draw its claim upon said appropriation in favor of the United States of America or the appropriate agency thereof for the payment of the cost of such portion of said cooperative work as may be determined by the department of public works.

SEC. 3. Upon the sale of any bonds of this state hereafter authorized to be issued to be expended for any one or more of the purposes for which any part of the appropriation herein provided may have been expended, the amount so expended from the appropriation herein provided shall be returned into the general fund of the state treasury out of the proceeds first derived from the sale of said bonds.

CHAPTER 656, STATUTES OF 1929

An act providing money for the study of the flood problems of the Santa Ana river system, the preparation of plans and specifications in connection therewith, providing for study of rainfall penetration in connection therewith, and establishment and maintenance of gauging stations, providing for the cooperation by interested counties and districts, and directing the division of engineering and irrigation, department of public works, to provide for the carrying on of said work under its own direction or under the direction of the department of agriculture of the United States, and relating thereto.

[I object to the item of twenty-five thousand dollars in section 1 and reduce the amount to fifteen thousand dollars. With this reduction I approve the bill. Dated: June 3, 1929. C. C. YOUNG, Governor.]

The people of the State of California do enact as follows:

SECTION 1. The sum of twenty-five thousand dollars or so much thereof as may be necessary is hereby appropriated out of any money in the state treasury not otherwise appropriated, which said sum shall be expended in and for the study of the flood problems of the Santa Ana river system and the study of rainfall penetration in connection therewith, and for the establishment and maintenance of gauging stations upon said river system, said work to be done under the direction of the division of engineering and irrigation, department of public works, and in conjunction with the department of agriculture of the United States of America; provided, however, that such sum shall become available and be disbursed from time to time in such amounts not exceeding said sum of twenty-five thousand dollars, as shall be matched or made available by any political subdivision or subdivisions within the State of California, or by the federal government, or by any other interested party, district or agency.

FOREWORD

This report is one of a series of bulletins on the State Water Plan issued by the Division of Water Resources pursuant to provisions of Chapter 832, Statutes of 1929, directing further investigation of the water resources of California. The series includes Bulletin Nos. 25 to 36, inclusive. Bulletin No. 25, "Report to Legislature of 1931 on State Water Plan," is a summary report on the entire investigation.

Prior to the studies carried out under this act, the water resources investigation had been in progress more or less continuously since 1921 under several statutory enactments. The results of the earlier work have been published as Bulletin Nos. 3, 4, 5, 6, 9, 11, 12, 13, 14, 19 and 20 of the former Division of Engineering and Irrigation, Nos. 5, 6 and 7 of the former Division of Water Rights, and Nos. 22 and 24 of the Division of Water Resources.

This bulletin is one of two pertaining to investigations of the water resources of the state prepared cooperatively by the Division of Agricultural Engineering, United States Department of Agriculture, the University of California Agricultural Experiment Station, and the Division of Water Resources of the State Department of Public Works.

Important phases of the general investigation, particularly in southern California, have been the estimation of the amounts of water contributed to underground reservoirs from direct rainfall on the valley floor, consumptive use of water by crops and native plants and loss of water from moist areas. This bulletin presents the results, so far available, of cooperative studies undertaken, pursuant to provisions of Chapter 656, Statutes of 1929, to determine quantitatively various sources of loss from and supply to the underground water in the Santa Ana Basin occurring in the valley floor. While the data presented are in the form of a progress report, it is believed that the information obtained is of sufficient value to warrant its publication at this time. It is planned to continue and extend these studies.

The bulletin is in two parts. Part I deals principally with penetration of rainfall and consumptive use of water and Part II with the loss of water from moist areas.

PART I

RAINFALL PENETRATION AND CONSUMPTIVE USE OF WATER ON VALLEY FLOORS

CHAPTER I

INTRODUCTION AND SUMMARY*

In southern California an increasing demand for water from underground supplies for irrigation, domestic and industrial purposes has created a need for more definite and accurate information on the consumptive use of water by plant life on irrigated and unirrigated lands and the contributions of rainfall on the valley floors to the ground water. The irrigation water requirements of crops are dependent on the amount and distribution of rainfall. The time of the first summer irrigation depends on the amount of soil moisture stored within the root zone at the end of the rainy season. The need for winter irrigation depends on whether or not the rains are sufficient to replenish the fall deficiency in soil moisture and meet the water requirements of the crops that grow during the rainy season. The annual irrigation requirements, therefore, are of necessity interrelated with rainfall, the primary purpose of irrigation being to maintain proper soil moisture conditions for crop production. In the past, soil moisture studies related to irrigation requirements have been confined mainly to the period between the last effective rain in the spring and the first effective rain in the fall. In this report an attempt is made to follow the soil moisture conditions throughout the year, with special emphasis on the less explored field of winter conditions.

When new land is brought under irrigation, the net increased draft on the irrigation water supply depends to a certain extent on the amount of rainfall formerly consumed by the uncultivated native growth. This amount of moisture which would have been used by the natural growth must be subtracted in obtaining the net increased draft on the water supply caused by placing land under irrigation. The penetration of rainfall and consumptive use of water on uncultivated land were therefore studied especially with reference to the draft on the irrigation water supply.

At the request of the State Engineer of California, a cooperative investigation was started in December, 1927, by the Division of Agricultural Engineering, Bureau of Public Roads, U. S. Department of Agriculture, to determine the disposition of rain falling on the valley floors of the Santa Ana River area in Orange, Riverside, and San Bernardino counties.

The four factors that combine in disposing of rainfall are (1) surface run-off, (2) evaporation, (3) transpiration, and (4) percolation. Under ordinary topographic and soil conditions, a part of the precipitation

* Part I was prepared by Harry F. Blaney, irrigation engineer, and C. A. Taylor, assistant irrigation engineer, under the general supervision of W. W. McLaughlin, associate chief of the Division of Agricultural Engineering, U. S. Department of Agriculture.

runs off from the surface of the land and eventually reaches the main drainage channels. That portion retained temporarily in the top layer of the soil or intercepted by plants is returned to the atmosphere by evaporation. Of the water which percolates into the ground, a portion is stored in the soil within the root zone and subsequently is transpired by plants, while the remainder penetrates below the root zone and joins the ground water. The amount penetrating to ground water may be determined indirectly if values are established for the other three factors entering into the disposition of rainfall, since all water penetrating below the root zone and beyond capillary reach of plant rootlets and evaporation must ultimately reach ground water, excepting only moisture lost in the form of vapor due to the circulation of air in the soil below the root zone. This loss is very small and is disregarded in the following discussion.

Fortunately, in southern California nature has created large underground reservoirs by filling deep basins with porous alluvial material. These natural underground reservoirs regulate the water supply derived from erratic precipitations by accumulating and storing the water of wet years for use in dry periods. The storage capacity of underground reservoirs of this character is enormous in comparison to that of artificial surface reservoirs. These underground basins are replenished by the percolation of rain falling directly upon the valley floors, seepage from streams traversing the valleys, flood waters discharging over alluvial fans, artificial water spreading, return waters from irrigation and in other ways.

After careful consideration of several methods, it was decided to study the problem mainly from a soil moisture standpoint by taking soil samples to a depth below the root zone. Rainfall penetration stations were established on predominating soil types and studies made of rainfall, run-off, transpiration, evaporation and depth of penetration. The location of these stations is shown on Plate I.

This investigation is still under way and will be continued. The purpose of this progress report is to present a portion of the data collected to September 1, 1930, and to describe methods and procedure followed, rather than attempt to give definite conclusions based upon the data thus far obtained. It is not intended at this time to show the relation of these basic data to the annual irrigation requirements. More detailed studies are being conducted on the water requirements of irrigated crops and will be published later.

Definition of Terms.

Apparent Specific Gravity (Volume Weight).—The ratio of the weight of a unit volume of oven-dry soil of undisturbed structure to that of an equal volume of water under standard conditions.

Field Capacity.—The amount of water retained in a previously saturated soil after the gravitational water has drained away freely. (Following an application of water to a saturation stage there is a more or less definite period during which the drainage of the water is comparatively rapid. After this a stage is reached where the water movement becomes comparatively slow, though continuing. The moisture still retained by the soil at the time when this change in rate of movement occurs is the field capacity of that soil.)


117°00'
45'
15'
34°00'
45'
33°30'
Bear Lake
RIVER
ANA
SANTA
Plunge Cr.
Mill
Creek
RDINO
REDLANDS
BEAUMONT
San
Timoteo
Canyon
79
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N
SANTA ANA INVESTIGATION
GENERAL MAP
RAINFALL PENETRATION
STATIONS
SCALE
0 1 2 3 4 8 12 MILES

runs off from the surface of the land and eventually reaches the main drainage channels. That portion retained temporarily in the top layer of the soil or intercepted by plants is returned to the atmosphere by evaporation. Of the water which percolates into the ground, a portion is stored in the soil within the root zone and subsequently is transpired by plants, while the remainder penetrates below the root zone and joins the ground water. The amount penetrating to ground water may be determined indirectly if values are established for the other three factors entering into the disposition of rainfall, since all water penetrating below the root zone and beyond capillary reach of plant rootlets and evaporation must ultimately reach ground water, excepting only moisture lost in the form of vapor due to the circulation of air in the soil below the root zone. This loss is very small and is disregarded in the following discussion.

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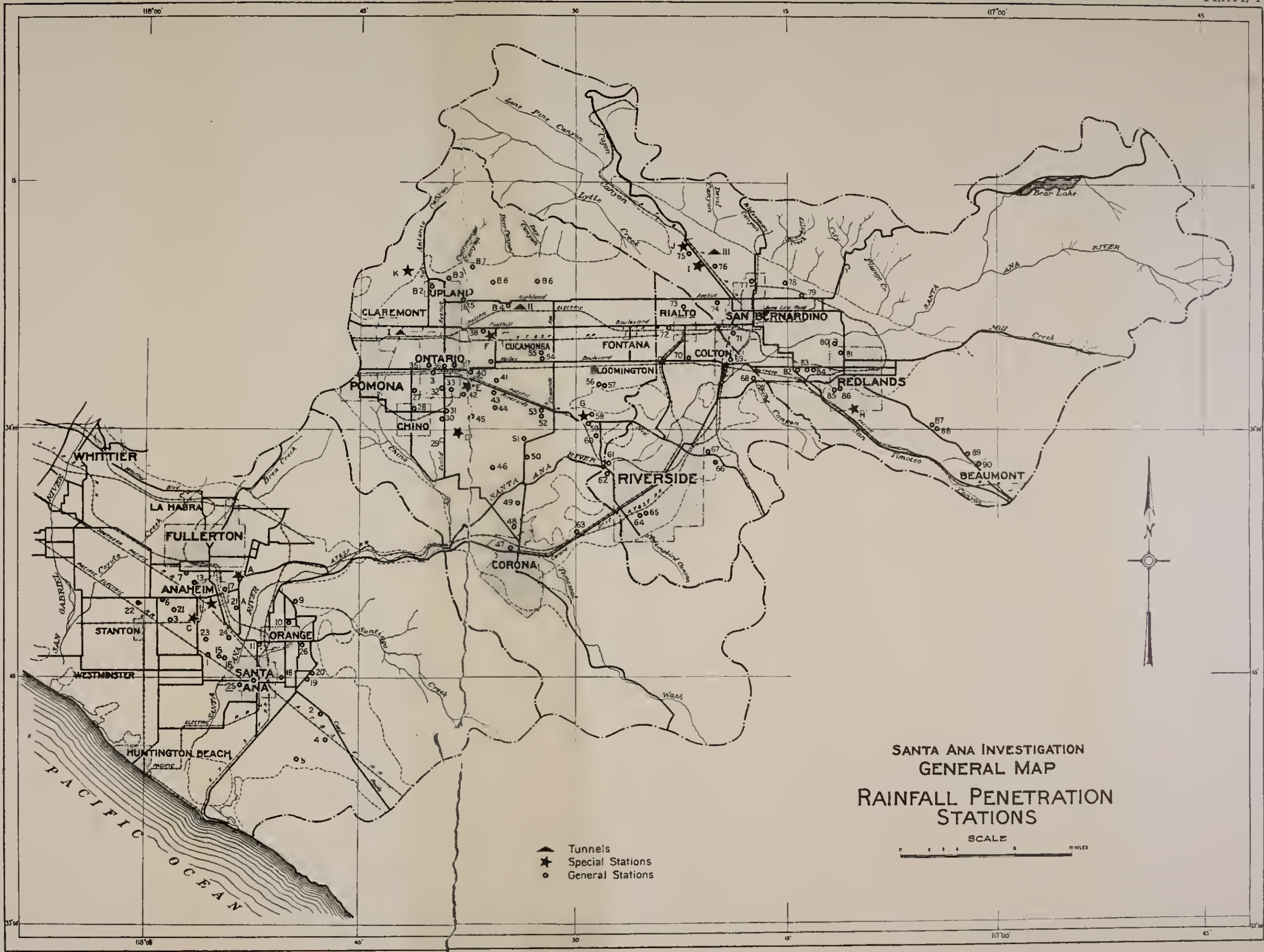
SANTA ANA INVESTIGATION
GENERAL MAP
RAINFALL PENETRATION STATIONS
SCALE
Tunnels
Special Stations
General Stations
PACIFIC OCEAN
WHITTIER
LA HABRA
FULLERTON
ANAHEIM
STANTON
WESTMINSTER
SANTA ANA
ORANGE
HUNTINGTON BEACH
POMONA
CLAREMONT
UPLAND
ONTARIO
CHINO
CUCAMONGA
FONTANA
BLOOMINGTON
RIALTO
SAN BERNARDINO
COLTON
REDLANDS
RIVERSIDE
CORONA
BEAUMONT
Bear Lake
SANTA ANA RIVER
Lytle Creek
Mill Creek
N

Consumptive Use.—The sum of water used by the vegetative growth of a given area in transpiration or building of plant tissue and that evaporated from that area.

Initial Fall Moisture Deficiency.—The amount by which the actual moisture content of a given soil zone (usually the root zone) is less than field capacity at the beginning of the rainy season.

Acre-Inches Per Acre.—The amount of water, expressed in inches of depth, over the given area. (The term is usually applied to water used in irrigation and is synonymous with the term "inches" as applied to rainfall.)

Transpiration Use.—The total amount of water, within the limits of field measurements, that is drawn from the soil directly by plant root action.

Soil Moisture Percentages.—This term refers to percentages of moisture in the soil, based on the weight of oven-dry material.

Summary.

1. The results of the last three years' work on brush plots indicate that a seasonal precipitation of at least nineteen inches is necessary before any material amount of water will penetrate below the brush root zone of the valley floors. A seasonal rainfall of less than nineteen inches is usually consumed by the brush covered area before the ground water receives any increment.

2. None of the grass and weed plots under observation in 1927–28 showed any penetration below the root zones. These plots, however, were selected in locations where the soil was deep and best suited for accurately determining the winter rates of evaporation and transpiration. In the 1928–29 and 1929–30 experiments, the grass and weed plots in the coarser soil types showed deep penetration below the root zone. Such penetration may be expected under these conditions after from ten to twelve inches of seasonal rain have fallen. When the soil supports a denser grass and weed cover, the consumptive use indicated is twelve to fifteen inches before deep penetration takes place.

3. In the 1929–30 season, the average penetration of rainfall below the root zone in three citrus plots was 5.8 inches. The average rainfall at these three plots was seventeen inches.

4. Unirrigated deciduous orchards that were in poor condition due to lack of care or poor soil were found to be relatively shallow rooted, while the more vigorous orchards and vineyards showed root activity to from fifteen- to eighteen-foot depths. The poorer orchards showed deep penetration below the root zone after eleven inches of seasonal rain, while some of the more vigorous orchards showed capacities for more than eighteen inches of rain without deep penetration below the root zone. Penetration in the winter-irrigated areas was dependent largely on the time and amount of irrigation.

5. Studies of the consumptive use of water along stream channels show that moist land growth bordering a stream channel has a marked influence on the flow of the stream. There is a daily fluctuation in flow to meet the transpiration demands of the bordering plant growth and a seasonal decrease in flow as the transpiration rate increases. The peak

demand of transpiration on the water of a stream may be expected in July and August. Air temperature is shown to be a direct indicator of the transpiration rate and hence of the effect of transpiration on stream flow. High temperatures cause extremely high rates of transpiration and correspondingly low stream flows.

6. During the winters of 1927-28, 1928-29 and 1929-30 there was no measurable run-off from undisturbed recent alluvial soil with native brush cover on the valley floor. Certain cropped areas, particularly in the Riverside district, showed noticeable run-off. It is indicated that, in the Riverside area of ancient alluvial soil type, the principal contribution of rainfall on the valley floor to the ground water comes from surface run-off. The average seasonal rainfall of the Riverside area is too low to cause any direct penetration below the root zone, except possibly in heavily irrigated citrus areas.

General Description of Area.*

The watershed of Santa Ana River has a total length of 100 miles and drains 2050 square miles. Of this area, 1196 square miles are mountains, foothills and isolated hills and 854 square miles are main valley floor. Thus, 42 per cent of the entire watershed is in gravel, sands and silts, generally water absorbing and water bearing. Four-fifths of the habitable area of some 1000 square miles is about equally divided between San Bernardino and Orange counties. Except for a small area in Los Angeles County, the remaining portion lies in Riverside County.

Of the total habitable area, 342,700 acres are now under irrigation; 25,282 acres are in domestic use; 21,218 acres are in river beds and waste lands, and about 250,800 acres are usable in the future. The rate of increase of domestic and irrigation area for the historic period is 8000 acres per year, and for the last eight years, apparently 21,000 acres per year.

The assessed valuation of the habitable area is $263,000,000. Within it are operating 78 water organizations with a total service area of 191,500 acres, some with use dating back half a century. In addition 207,100 acres are occupied by individuals not so organized.

Santa Ana Valley consists of a series of basins, mesas and hills. The basins are filled with detritus brought down from the precipitous mountains by the sudden violent floods of the region. They are separated, one from the other, by hills and mountain ranges or by underground barriers, such as Bunker Hill Dike, crossing the valley between San Bernardino and Colton.

Upper Basin is defined by Bunker Hill Dike. It could be divided into East Upper, Lytle Creek and Yucaipa-Beaumont subbasins. Jurupa Basin might be divided into Colton and Riverside mesas. Cucamonga Basin could be divided into Upper and Chino and these could be even further subdivided. These subdivisions are suggested by changes in character of valley fill which create changes in water conditions. Temescal Basin is not of great effect in its regulation of or contribution to the underground water supply, and no notation is made of possible subdivisions. Lower Basin or coastal plain has an

* Abstracted in part from Bulletin No. 19 (1929), "Santa Ana Investigations," published by former Division of Engineering and Irrigation, State Department of Public Works.

upper percolating area and a lower nonpercolating area. The most definite division between basins is the mountain range separating the coastal plain from the remainder.

Santa Ana River (plus Mill Creek) discharges 43 per cent of the total surface mountain run-off. Even with this concentration, water flows from the mountains to the ocean only during or a short time after a heavy rain. In all the remainder of the time the stream is absorbed in the porous detritus across which it flows. Water percolates to the underground water plane and travels slowly in the direction of the flow of the surface stream until a barrier, either underground or surface, pushes it to the surface as rising water. Below the barrier another basin is crossed, percolation takes place and again the underflow becomes rising water at the next barrier.

On Santa Ana River, the first percolating area in Upper Basin begins at the mouth of the canyon and extends to a point seven miles below the mountains where Bunker Hill Dike begins to make its presence felt and where water is forced to the surface for a distance of six miles. Then comes another percolating area seven miles long in Jurupa Basin. Then above Riverside water is again brought to the surface and this increases in amount for eighteen miles until it enters the lower Santa Ana Canyon, through the upper third of which it remains fairly constant but below which point it commences to show a decrease. Seventeen miles of the coastal plain ending at a point near Santa Ana comprises the third percolating area. The region between that area and the ocean formerly must have been an area of rising water, but the present diminished pressures no longer cause rising water. However, the surface water plane is perched on impervious strata, thus preventing percolation. The percolating areas in the Upper Basin, in Colton subbasin and in the coastal plain are the important ones.

These basins of vast unconsolidated gravel fills constitute reservoirs from which most of the water supplies of the region are drawn by means of pumps. They are supplied by percolation from streams that cross them, by percolation from rain on the valley floor itself and by percolation from irrigation. They absorb the heavy flows and rains of the wet years and hold them for the dry years. The characteristic of the climate is the large annual and cyclic variation in precipitation and run-off, and this is ironed out and equated by these underground reservoirs. Without them the economic development of the region would have been impossible. This may be inferred from the fact that 90 per cent of the water supplies are derived from them either by pumps or by gravity diversions of rising water, due to and regulated by them, and from the fact that only 10 per cent of the mountain run-off escapes into the ocean because of their absorptive and retentive qualities. Above present water levels, it is estimated 1,500,000 acre-feet of water have been stored in them at the highest level of historical times and through the action of nature alone. A conservation program will adopt nature's method of storage and seek to make it more efficient.

CHAPTER II

METHODS AND EQUIPMENT

Rainfall Penetration Stations.

With a view to making an intensive study of rainfall penetration, a large number of stations have been established on predominating soil types in Orange, Riverside and San Bernardino counties. The majority of these stations, both on irrigated and nonirrigated tracts, are located at points where the ground water is so far below the surface that capillary action will have no influence on the moisture content of the soil studied. A few of the stations, however, are located where depths to ground water are approximately fifteen feet. Ten stations are especially equipped for intensive work, and measurements of rainfall, surface run-off, soil moisture deficiency, evaporation, transpiration and depth of penetration are made at these stations.

Soil moisture conditions of the valley floor tracts usually can be studied through the aid of standard soil sampling tubes, and the storage of rain water in the soil and the downward percolation of the water thus determined. The alluvial fans or deltas occurring at points where drainage channels debouche from the mountains, however, are full of gravel and boulders which make the use of soil tubes impracticable, and where these conditions prevail shafts have been sunk to depths below the root zones. From these shafts tunnels have been driven laterally where desired and soil samples are taken from the sides of the shafts and tunnels. At one station of this kind near Devil Canyon, north of San Bernardino, artificial rain was applied during the 1927–28 and 1928–29 seasons and the downward movement of water observed in tunnels twelve and twenty feet, respectively, below the ground surface.

A part of the surface run-off from the valley floors may be termed local as it flows directly into depressions and then percolates into the ground without reaching the main surface streams.

The method of measuring local surface run-off on uncultivated land with native vegetation is to collect the run-off of small areas of 100 square feet and measure it volumetrically. Measurements of run-off from agricultural areas are made by installing Parshall flumes with recorders in drainage ditches. Areas of from two to twenty acres are used in the plots. Records of rainfall intensity are kept by recording rain gages in connection with these tests.

The direct penetration, as well as the surface run-off of any one season's rainfall, depends on the initial moisture conditions at the beginning of the rainy season and the amount of evaporation and transpiration occurring during that season. These factors vary with the cover, but the area under consideration can be classified according to crops grown. Citrus trees are shallow-rooted and cause a small initial deficiency of soil moisture in the fall, but vines, deciduous trees and native brush are deep-rooted and use the soil moisture to greater depths, thus causing a large initial fall moisture deficiency.

Soil moisture studies are relied upon to determine values for the initial fall moisture condition and subsequent evaporation and transpiration losses. With these factors known, the rainfall penetrating below the root zone can be calculated.

Soil Moisture Studies.

Since a large part of the rainfall entering the soil is lost by evaporation and transpiration, field plots having either cultivated crops or native vegetation are being studied intensively throughout the year to determine such losses. The improved soil tube* is used for obtaining soil samples for moisture determination.

Soil samples are taken in one-foot sections to depths of from twelve to eighteen feet, reaching soil conditions well below the major root zone of most native and crop plants. The drying of the samples is done in an electric oven operated at 110 degrees Centigrade. In general, standard laboratory practices are used in determining the moisture content.

A great number of soil samples must be taken in this work, often to depths of about eighteen feet. The work is greatly expedited by using an air hammer to drive the soil tube and a jack to withdraw it from the soil. Both the applications of the air hammer and jack were developed in connection with this investigation.

The equipment is shown in Plate II and consists of a compressed air unit, soil tube and soil tube jack. The compressed air unit includes a compressor unit mounted on a truck, a light air hammer and a 100-foot length of one-half-inch rubber hose.

The air hammer† for driving the tubes is of the clay-spader type and requires 40 cubic feet of air per minute at an operating pressure of 100 pounds per square inch. At this pressure, the hammer delivers about 2250 blows per minute, each blow striking with a force of sixteen foot pounds. The air supply for this unit is furnished by a duplex compressor with direct coupled gas engine drive, equipped with a self-starter.

The soil tubes used range from 5.5 to 25 feet in length and consist of sixteen-gage seamless steel tubing fitted with a suitable driving head and point.

The cutting point is made of case hardened nickel steel and has a choke bore so that the soil core slides up inside the tube without serious attendant friction.

For the purpose of pulling the soil tubes from the ground a new type of jack‡ was perfected. The jack is light and simply made, and is very effective in its operation. It is shown in the foreground of Plate II. Depths of 25 feet are practicable with the present equipment. Use of the apparatus is found impracticable in soil containing stones of diameters greater than two inches. Also the soil tube is not suited for

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* An improved soil-sampling tube, by F. J. Veihmeyer, Soil Science; Vol. XXVII, No. 2 February, 1929.

† "An Efficient Soil Tube Jack," by C. A. Taylor and H. F. Blaney, Soil Science; Vol. XXVII, No. 5, May, 1929.

‡ "Soil Sampling With a Compressed Air Unit," by H. F. Blaney and C. A. Taylor, Soil Science; Vol. XXXI, No. 1, January, 1931.

use in heavy clays that are wet enough to become plastic, as the core sticks to the walls of the tubing.

Most of the valley floor area can be sampled with these tools, but the high alluvial fans are full of coarse rocks and boulders and dug shafts and tunnels must be resorted to.

When the soil is very rocky, it is necessary to take large portions of the material in order to get representative samples. Accordingly, when it is necessary to resort to dug pits, 4000 gram samples are taken of the material as it occurs in place, without selection as to size of

PLATE II

SOIL SAMPLING EQUIPMENT

particles. All samples are weighed to the nearest one-tenth of a gram and oven-dried at 110 degrees Centigrade. After drying, the rocky samples are screened in a mechanical shaker to a screen with two millimeter openings. All material retained on the two millimeter screen is classed as rock. Moisture content then is computed from two bases: one, the oven-dry weight of the entire sample; the other, the oven-dry weight of the soil in the sample with all particles above two millimeters in diameter excluded.

When converting the percentage of moisture in the soil to equivalent depth of water in inches, it also is of value to have two bases for the determination of the apparent specific gravity. Accordingly, samples are obtained by cutting out cores of from 0.5 to 1.5 cubic feet of material as it occurs in place. The entire core is oven-dried and the apparent specific gravity of the natural material obtained. The entire sample then is screened and a second apparent specific gravity determined, based on the weight of the soil particles below two millimeters in diameter as they occur in place in the field. In the second case, the rocks are regarded as space filler only and the moisture is considered as being held by the soil. This assumption that all of the moisture is held by the soil and none by the rock content is not strictly correct, especially when the moisture content of the material is near field capacity. However, in the conversion from moisture percentage to depth in inches the effect of excluding the rock in the calculations is merely to reduce the value of the apparent specific gravity and increase the percentage of moisture correspondingly.

The equations are:

$$D = \frac{PVd}{100} = \frac{P_s V_s d}{100}$$

where D is the equivalent depth of water in the soil, in inches;

- d the depth of the soil sample considered, in inches;
- P the percentage of moisture in the soil based on the oven-dry weight of the entire sample;
- V the apparent specific gravity of the material in place;
- P_s the percentage of moisture based on the oven-dry weight of the soil in the sample with rock excluded;
- V_s the apparent specific gravity of the soil content in place with the rock excluded.

The advantage of using the relation on the screened basis lies in the fact that smaller samples may be used for regular sampling after the relationship is established for a particular plot. When large samples are taken and both methods used, a double check is obtained.

In the intensive studies in orchards, seventeen holes are usually put down within a square of four trees and samples taken at two-week intervals. For an absolute check on the winter transpiration by citrus, a covered plot was established in one grove. A tent was placed on a frame under the tree branches in a square of four trees so that the soil was protected from rain within the square and to a distance of eight feet beyond each side of the square. Soil moisture records could then be kept without the interference of frequent rains. A record of soil moisture extraction was kept on this plot throughout the calendar year.

In order to determine definitely what happens to the soil moisture below the root zone, two plots have been established on typical soil types. Water was applied over a 20-foot square in sufficient amount to wet the soil to a depth of at least eighteen feet. A twelve-foot square in the center of this plot then was boarded over and sealed with roofing paper. Boards were extended one foot into the soil around the edge of the sealed area. The whole 20-foot plot then was roofed over with corrugated iron to protect the plot from rain. The ground is kept clear of vegetation for a distance of 30 feet around the plot and a trench five feet deep dug around the cleared area to guard against interference from roots. Soil samples are taken in foot sections, to a depth of eighteen feet at frequent intervals in the sealed area. Holes are bored through the roof and sealed again after the samples are obtained. It is intended that this experiment shall continue for at least two years, or longer if results indicate a continued drainage or loss of soil moisture.

Evaporation from the soil has been carefully measured after each rainstorm throughout the season. The method followed was to select an area of deep dry soil in the fall of the year and then keep all plant growth cleared off throughout the rainy season. Trenches were dug to obtain the wetted outline of rainfall penetration and samples were taken for moisture content. Evaporation losses could be computed from these data.

The final summation of the penetration of rainfall to the ground water is made after values have been established for the aforementioned factors, namely, the run-off, the initial fall deficiency of soil moisture for each crop, the transpiration requirements of each crop and the evaporation losses.

CHAPTER III

AREAS OF NONIRRIGATED LAND

BRUSH

Devil Canyon Shaft Plot.

In the latter part of February, 1928, certain investigations were started in cooperation with the Municipal Water Department of the city of San Bernardino to study the penetration of rainfall below the root zone, the storage in the soil of rain water and the consumptive use of water by brush on the valley floor.

PLATE III

DEVIL CANYON PLOT, SHOWING BRUSH COVER AND MATERIAL FROM SHAFT. NOVEMBER, 1928.

The board of water commissioners of the San Bernardino Municipal Water Department furnished funds for building a shaft and tunnels in the gravel area of the valley floor south of Devil Canyon. Under the supervision of William Starke, superintendent of the San Bernardino Water Department, a shaft 26 feet deep and two 20-foot tunnels, one running north twelve feet below the ground surface and the other running west at the 20-foot level, were excavated. Two types of collector pans were placed in the roofs of the tunnels to intercept rain water and on April 20, 1928, an overhead sprinkler system was installed and in 1928 and 1929 artificial rain was applied.

When the shaft was dug, the native brush cover on the experiment plot, mainly chamisal, sage, wild olive, squaw berry, cactus and yucca, was moderately heavy in comparison with the general valley floor cover. Plate III shows the brush cover as left permanently in its natural condition and the material from the shaft so placed as not to interfere with rainfall penetration.

Observation made when the shaft was dug indicated a depth of sixteen feet of root activity for the brush present. This has been confirmed by the results of soil sampling obtained during the past three years. Some dead roots were found at eighteen feet. The brush has not been burned within 25 years.

During the last three seasons, the downward movement of water was observed in the tunnels. The square collector pans intercepted part of the moisture moving downward through the soil. However, the amount was not a quantitative measure of the deep penetration as shown from soil sampling, but satisfactory records were kept of the moisture content of the soil by excavating into the sides of the tunnels at various levels and taking samples of the material. Samples of the soil above the tunnels were taken in foot sections with standard soil tubes. From these data the penetration of rain below the root zone and the consumptive use of water by brush were computed.

A summary of the results of each season, 1927–28, 1928–29 and 1929–30, is given in Table 1. Other brush plots are being studied and the investigation is not complete. However, the results indicate the proportion of rain penetrating below the root zone is largely dependent on the magnitude and seasonal distribution of the rain storms.

TABLE 1

PENETRATION BELOW ROOT ZONE AND CONSUMPTIVE USE OF WATER AT DEVIL CANYON PLOT, SAN BERNARDINO

Season	Natural rainfall in inches	Artificial rainfall in inches	Total rainfall in inches	Deep penetration below root zone			Evaporation and transpiration in inches
				From natural rain in inches	From artificial rain in inches	Total penetration in inches	
1927-28	17.67	[1]14.33	32.00	None	5.0	[1]5.0	27.0
1928-29	16.33	8.49	24.82	None	6.0	6.0	18.8
1929-30	20.90	None	20.90	1.8	None	1.8	19.1

[1] The artificial rainfall was applied as given in Table 5, but usually most of the natural rainfall occurs before April 15. If the 14.33 inches of artificial rain had been applied before April 15, undoubtedly ten inches of rain or more would have penetrated below the root zone instead of five inches as given.

Analyses of Material.—During the construction of the shaft and tunnels, 10,000-gram samples of material were taken from each foot section of the shaft and at typical locations in the tunnels. Smaller samples (600-gram) of the finer material, from which the coarser rocks had been excluded, also were collected. The samples were oven-dried at 110 degrees Centigrade for moisture content determination, and specific gravity determinations and mechanical analyses were made. The moisture content of the material showed that the depth of rainfall penetration at the time of digging the shaft averaged eight and one-half feet in the shaft and eleven feet in the north tunnel.

Mechanical Analyses.—The following method was used in making the mechanical analyses:

The samples were oven-dried and in each determination the entire sample (about 10,000 grams) was screened down to the No. 4 sieve inclusive (Tyler standard). A 500-gram sample was then selected by twice quartering the part of the sample which passed the No. 4 sieve. This 500-gram sample then was used for sieves Nos. 8 to 200 inclusive. The values given are expressed as percentages of the entire weight of the sample. The analyses were made in a mechanical shaker and sieved to the point of practical refusal. The results are given in Table 2.

TABLE 2

MECHANICAL ANALYSIS OF MATERIAL TAKEN FROM DEVIL CANYON SHAFT, SAN BERNARDINO, 1928

Depth of sample in feet	Per cent of material retained on screens of following sizes											Per cent of material passing screen No. 200
	3 inch	1.50 inch	.742 inch	.371 inch	No. 4	No. 8	No. 14	No. 28	No. 48	No. 100	No. 200	
1	0	0	6	5	3	4	6	10	17	21	14	14
2	0	0	5	4	5	5	7	11	17	21	14	11
3	0	18	18	13	11	7	8	9	8	5	2	1
4	0	7	19	11	7	6	9	15	18	6	1	1
4- 6	0	8	9	8	9	8	10	14	16	12	4	2
6- 8	6	18	12	8	8	6	10	13	12	5	1	1
8-10	5	14	11	9	7	8	13	15	10	5	2	1
10-12	0	11	11	7	8	9	13	16	14	7	2	2
12-14	5	17	19	12	8	6	8	11	9	3	1	2
14-16	13	9	14	8	7	7	11	12	9	6	2	2
16-18	0	3	7	5	5	6	14	23	21	11	3	1
18-20	10	6	16	10	9	7	10	12	11	6	2	1
20-22	0	15	13	13	8	5	7	10	14	10	3	2
22-24	0	11	19	12	10	7	10	11	10	6	2	2
24-26	0	12	11	9	8	7	9	11	12	12	5	4

Apparent Specific Gravity.—When the shaft was dug, samples of the material excavated were taken at one-foot intervals to the depth of 26 feet for apparent specific gravity determination. These were made by rodding the oven-dried material into a cylinder six inches in diameter and six inches deep. The cylinder was filled by thirds and each third was rodded 25 times. The weight of the material required to fill the cylinder divided by the measured volume of the cylinder gives the apparent specific gravity (volume weight). This method was modified somewhat when a sample contained material larger than three inches in diamenter. The volume of the large rocks then was computed separately and corrections made on the cylinder determinations. The average apparent specific gravity from the surface to a depth of two feet was 1.76; from two to six feet, 2.02; and from six to eighteen feet, 2.04. Detailed results are as follows:

Depth in feet	Apparent specific gravity	Depth in feet	Apparent specific gravity	Depth in feet	Apparent specific gravity
0-1	1.75	6- 8	2.06	16-18	1.87
1-2	1.77	8-10	2.08	18-20	2.13
2-3	2.04	10-12	1.99	20-22	2.07
3-4	1.99	12-14	2.08	22-24	2.11
4-6	2.02	14-16	2.13	24-26	2.00

Field determinations were made of apparent specific gravity on the undisturbed soil for the purpose of comparison with those made by laboratory method. The field determinations were made by collecting all the material from a hole approximately six inches in diameter and eight inches deep, and determining the volume of the hole from the amount of cold molasses required for filling it. The results are as follows:

Depth in feet	Apparent specific gravity		
	Laboratory	Field	Difference
1	1.78	1.62	+.16
4	1.76	1.67	+.09
18	1.70	1.78	—.08
26	2.15	2.20	—.05

A mechanical analysis of samples used is shown in Table 3.

The true specific gravities of material taken from the shaft from surface to 26 feet are given in Table 4.

TABLE 3

MECHANICAL ANALYSIS OF MATERIAL USED IN FIELD DETERMINATIONS OF APPARENT SPECIFIC GRAVITY

Depth of sample in feet	Per cent of material retained on screens of following sizes											Per cent of material passing screen No. 200
	3 inch	1.50 inch	.742 inch	.371 inch	No. 4	No. 8	No. 14	No. 28	No. 48	No. 100	No. 200	
1	0	2	5	3	3	2	5	9	20	23	14	14
4	0	0	5	4	5	4	6	10	17	23	14	12
18	0	0	3	2	5	8	15	29	24	10	3	1
26	31	16	10	8	7	5	5	7	6	3	1	1

TABLE 4

TRUE SPECIFIC GRAVITY OF MATERIAL TAKEN AT VARIOUS DEPTHS FROM DEVIL CANYON SHAFT, SAN BERNARDINO

Depth of sample in feet	Specific gravity[1]	Depth of sample in feet	Specific gravity[1]
0- 1	2.67	12-14	2.67
1- 2	2.66	14-16	2.66
2- 3	2.68	16-18	2.66
3- 4	2.66	18-20	2.66
4- 6	2.68	20-22	2.67
6- 8	2.67	22-24	2.66
8-10	2.67	24-26	2.67
10-12	2.67		
Average			2.67

[1] The true specific gravities were determined by finding the volume of kerosene displaced by 58 grams of the sample.

Artificial Rain.—Artificial rain was supplied by using sprinklers of the Campbell type set in a group equidistant from the ends of the two tunnels. No measurable wind blew during any of the applications so that reasonably uniform amounts were applied over the tunnels and to at least eight feet beyond the end of each tunnel. Much of the variation shown in the rain gage readings was due to the interception of rain by the brush. Applications were made between 6 p.m. and midnight as this was the time of least wind and evaporation was lowest.

The intensity of application varied from 0.75 inch to 1.25 inches per hour. No standing water was observed at any time during the runs in the natural, undisturbed brush area. Around the shaft where the ground was tramped down, small pools up to a foot in diameter formed after 40 minutes of application at the rate of 1.25 inches per hour, but no lateral surface movement occurred from these pools at the end of one hour. The pools disappeared at the end of fifteen minutes after the rate was cut to one inch per hour.

The air temperature in the sprinkled area varied from 45 to 60 degrees Fahrenheit during the artificial rain storms. In 1928, records were kept of the evaporation by means of a standard U. S. Weather Bureau pan located 90 feet from sprinklers. The loss of water by evaporation during each artificial rain was as follows:

April 24, 0.03 inch; April 28, 0.04 inch; May 5, 0.05 inch; and May 23, 0.05 inch.

The artificial rainfall records for 1928 are given in Table 5.

TABLE 5

ARTIFICIAL RAINFALL RECORDS AT DEVIL CANYON SHAFT, SAN BERNARDINO, 1928

Location	Gage No.	April 24	April 28	May 5	May 23
		In inches	In inches	In inches	In inches
Gages over West tunnel	1	4.1	2.6	3.2	4.3
	2	3.6	3.0	3.5	4.4
	3	4.3	3.2	3.0	4.4
	4	5.1	2.9	3.7	4.5
	5	4.2	----	2.9	4.4
	6	4.5	3.0	3.0	3.6
	7	3.3	3.1	3.6	3.6
Average	----	4.16	2.97	3.27	4 17
Location	Gage No.	In inches	In inches	In inches	In inches
Gages over North tunnel	1	4.2	2.9	2.0	4.2
	2	----	3.0	3.0	4.0
	3	----	2.8	2.3	4.1
	4	3.9	3.0	2.9	4.1
	5	3.5	3.0	3.2	4.5
	6	3.5	2.5	5.3	3.9
	7	4.2	3.3	3.4	4.4
	8	----	2.8	3.7	4.6
	9	3.7	2.4	3.1	3.8
	10	----	2.6	3.6	4.1
Average	----	3.83	2.83	3.25	4.17
Average of all	----	4.00	2.90	3.26	4.17
Total	----	----	----	----	14.33

Disposal of Rainfall—Soil Moisture Deficiency.—Soil sampling done during the last three years indicates brush extracts moisture from the soil after wilting coefficient has been reached. The soil is classified as Hanford gravelly sandy loam and has a field capacity of about six per cent. The deficiency of moisture at the beginning of the rainy season is about one inch per foot in the top two feet of soil and three-fourths inch per foot at a depth of from two to sixteen feet. On this basis the moisture deficiency is twelve and one-half inches for a root zone of sixteen feet, eleven inches for fourteen feet, nine and one-half inches for twelve feet and eight inches for ten feet.

Run-off.—At six different times artificial rain was applied to the plot at the rate of from 1.0 to 1.25 inches per hour for periods of from three to five hours. No run-off occurred and pools did not form until the rate reached 1.25 inches per hour. The intensities of natural rainfall during the 1927-28, 1928-29 and 1929-30 seasons were not sufficient to cause run-off at any time.

Evaporation and Transpiration.—It is difficult to determine the consumptive use of water by plants during the winter months owing to the irregularity of rainfall, but at the end of the rainy season the transpiration use of water may readily be determined by soil moisture observations. Experimennts indicate that the average evaporation loss during each storm probably does not exceed 0.5 inch.

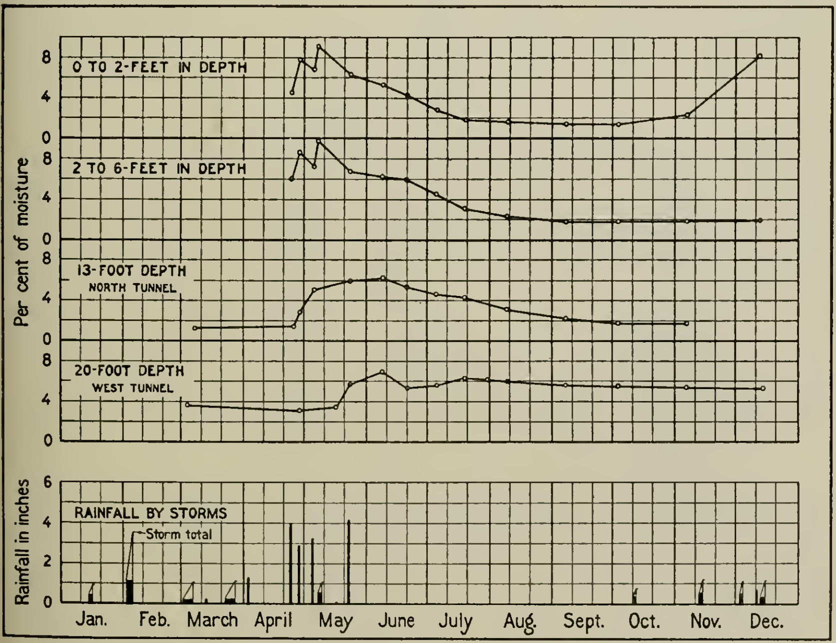
Season of 1927-28.—The total rainfall to February 21, 1928, at the shaft was 12.84 inches, of which 4.92 inches were stored in the top ten feet of soil, leaving 7.92 inches to be accounted for by evaporation loss and use of water by brush.

Previous to the first application of artificial rain on April 24, 16.54 inches of natural rain had fallen. The amount of moisture stored in the soil was about six inches and the remainder of the 16.54 inches of rain, about 10.5 inches, was lost by evaporation and transpiration.

From April 24 to May 23, 15.46 inches of artificial and natural rain fell on the plot. About 6.5 inches of this amount was required to make up the deficiency of soil moisture in the root zone. The consumptive use of water during this period was estimated at four inches. On this basis, five inches penetrated below the root zone. Thus, out of a total of 32 inches of natural and artificial rain during the 1927-28 season, 27 inches were lost by evaporation and transpiration. The results of the 1928-29 and 1929-30 seasons indicate that had all of the natural and artificial rain of the 1927-28 season occurred before the middle of April, as it usually does, at least five inches more of rain would have penetrated below the root zone.

The average soil moisture records are shown in Table 6 for 0-2 feet, and 2-6 feet, North Tunnel and West Tunnel. The rainfall data are given in Table 7. The transpiration use of water by brush during the summer was computed and is shown in Table 8. Plate IV shows the variation in moisture content at various depths.

PLATE IV



VARIATION IN MOISTURE CONTENT AT DEVIL CANYON PLOT, 1928.

TABLE 6

AVERAGE MOISTURE CONTENT AT DEVIL CANYON SHAFT, SAN BERNARDINO, 1928

Dates of sampling	Average moisture content of soil			
	0–2 feet	2–6 feet	North tunnel (13-foot level)	West tunnel (20-foot level)
	In per cent	In per cent	In per cent	In per cent
March 3				3.7
March 7			1.2	
April 24	4.5	5.9		
April 25			1.4	
April 28	7.7	8.4	2.8	3.1
May 5	6.7	7.1	5.0	
May 7	9.0	9.7		
May 16				3.4
May 23	6.3	6.7	5.9	5.7
June 8	5.3	6.2	6.2	6.9
June 20	4.2	5.9	5.3	5.3
July 5	2.8	4.5	4.7	5.6
July 19	1.9	3.0	4.3	6.3
August 9	1.6	2.3	3.1	6.0
September 7	1.4	1.8	2.2	5.7
October 3	1.4	1.9	1.8	5.6
November 6	2.3	1.9	1.8	5.5
December 12	8.1	2.0		
December 14				5.4

TABLE 7

RAINFALL RECORDS, 1927-28, DEVIL CANYON SHAFT AND NEWMARK RESERVOIR, SAN BERNARDINO

Date	At mouth of Devil Canyon in inches	At Newmark Reservoir in inches	At Devil Canyon shaft in inches
1927—			
October 26–November 1	4.71	3.56	4.14
November 6	.09	.05	.07
November 10–13	.99	.78	.89
December 10–14	2.62	1.90	2.26
December 25–29	.90	1.20	1.05
1928—			
January 15–16	0.76	1.08	0.92
February 3–5	3.51	3.51	3.51
March 2–6	1.06	1.04	1.05
March 13	.25	.21	.23
March 23–27	1.76	.90	1.12
April 3	1.50	1.05	1.30
May 8–9	1.27	1.11	1.09
May 17	T	.05	.04
Artificial rainfall—			
April 24			4.00
April 28			2.90
May 5			3.26
May 23			4.17
Total			32.00

TABLE 8

TRANSPIRATION USE OF WATER BY BRUSH AT DEVIL CANYON SHAFT, SAN BERNARDINO

June 8 to September 7, 1928

Period	Number of days	Depth in feet	Use of water: For period, Zone	Use of water: For period, Per foot	Use of water: Rate per 30 days
1928—			In inches	In inches	In inches
June 8–June 20	12	0– 2	0.46	0.23	1.15
June 8–June 20	12	2– 6	.22	.06	.55
June 8–June 20	12	6–16	.75	.08	1.88
June 8–June 20	12	0–16	1.43	----------	3.57
June 20–July 19	29	0– 2	0.97	0.49	1.00
June 20–July 19	29	2– 6	2.13	.53	2.20
June 20–July 19	29	6–16	1.82	.18	1.88
June 20–July 19	29	0–16	4.92	----------	5.09
July 19–August 9	21	0– 2	0.13	0.07	0.19
July 19–August 9	21	2– 6	.52	.13	.74
July 19–August 9	21	6–16	2.19	.22	3.13
July 19–August 9	21	0–16	2.84	----------	4.06
August 9–September 7	29	0– 2	0.08	0.04	.08
August 9–September 7	29	2– 6	.37	.09	.38
August 9–September 7	29	6–16	1.64	.16	1.70
August 9–September 7	29	0–16	2.09	----------	2.16
June 8–September 7	91	0– 2	1.64	0.82	----------
June 8–September 7	91	2– 6	3.24	.81	----------
June 8–September 7	91	6–16	6.40	.64	----------
June 8–September 7	91	0–16	11.28	----------	----------

Season 1928–29.—Soil sampling during 1928 indicated that the field capacity of soil was about six per cent. In the fall of 1928 the top two feet of soil reached a moisture content of 1.4 per cent, showing an initial deficiency of soil moisture of about one inch per foot of soil. From two to sixteen feet the moisture content averaged 1.8 per cent, showing a deficiency of about 0.75 inch per foot. On this basis the total moisture deficiency within the root zone, or top sixteen feet of soil, was 12.50 inches, and for the top ten feet, eight inches.

On April 1, a pit was dug to the depth of twelve feet about fifteen feet north of the plot. The total rainfall to that date had been 13.76 inches and it had penetrated to a depth of ten feet. Thus eight inches of rain was stored in the soil and 5.76 inches lost by evaporation and transpiration, as no run-off occurred.

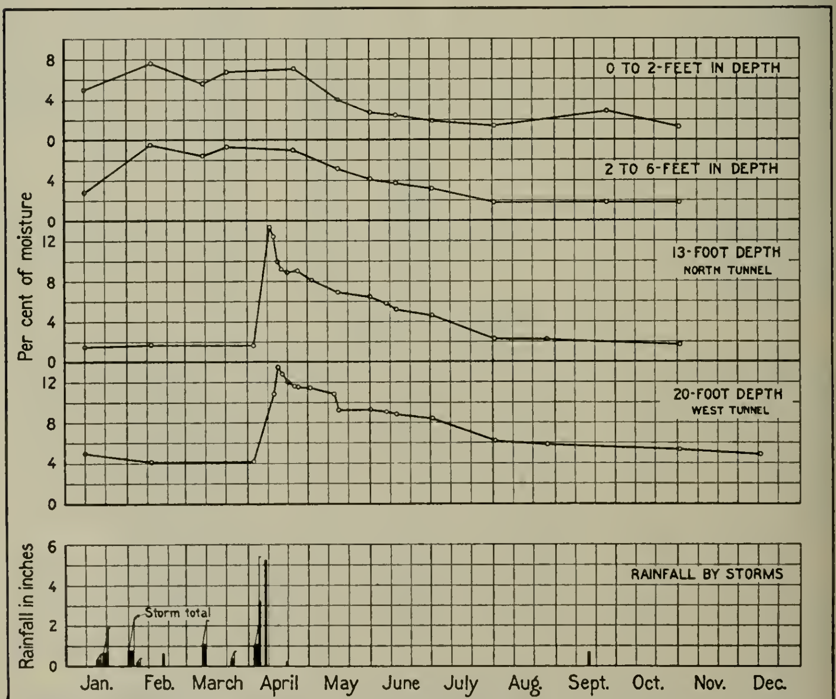
On April 4 and 5, 2.16 inches of rain fell. On April 6, 3.26 inches of artificial rain were applied, followed by 5.23 inches on April 8. The water was applied at night with overhead sprinklers at a rate of one inch per hour. There was no run-off. About 4.5 inches of this 10.65-inch storm were required to bring the remaining six feet of soil within the root zone (ten to sixteen feet) up to field capacity, leaving 6.15 inches to penetrate below the sixteen-foot level or root zone.

The field capacity of the soil below the root zone is about six per cent, or 1.09 inches per foot of soil. The average moisture content of the soil at the 20-foot level from April 15 to 17, was 13.15 per cent, or 2.40 inches per foot. Thus, when the soil drained to field capacity, 1.31 inches per foot would have passed below the root zone. Soil sampling indicated this occurred in the soil mass from sixteen to 20 feet. On this basis the four-foot section of soil would yield 5.24 inches to the ground water supply. Soil sampling over a longer period indicated there was a further drainage of 0.87 inches.

The above computations indicate that about six inches of water penetrated below the root zone as the result of the occurrence of 2.16 inches of natural rainfall on April 4–5, supplemented by the application of 8.49 inches of artificial rain on April 6 and 8, a total of 10.65 inches within less than five days.

Rainfall data for the 1928–29 season are shown in Table 9. In Table 10 is given the average soil moisture content. The transpiration use of water by brush during summer is shown in Table 11. Plate V shows the variation in moisture content at various depths.

PLATE V



VARIATION IN MOISTURE CONTENT AT DEVIL CANYON PLOT, 1929.

TABLE 9

RAINFALL RECORD, 1928-29, DEVIL CANYON SHAFT, SAN BERNARDINO

Date	Rainfall in inches	
	8-inch gage	3-inch gage
1928—		
October 11-12	0.79	------------
November 13-14	1.17	1.06
December 3-4	1.11	------------
December 11	.76	.72
December 13-15	1.16	1.08
1929—		
January 16-17	0.55	0.51
January 19-21	1.91	1.80
February 1-3	2.35	2.26
February 5-6	.36	.34
February 18	.59	.55
March 9-10	2.23	2.18
March 13	.07	.06
March 23-24	.71	.68
April 4-5	2.16	2.09
April 20	.41	.40
Total natural rainfall	16.33	------------
Artificial rainfall—		
April 6	3.26	------------
April 8	5.23	------------
Total	24.82	------------

TABLE 10

AVERAGE MOISTURE CONTENT AT DEVIL CANYON SHAFT, SAN BERNARDINO, 1929

Dates of sampling	Average moisture content of soil			
	0-2 feet	2-6 feet	North tunnel (13-foot level)	West tunnel (20-foot level)
	In per cent	In per cent	In per cent	In per cent
January 10	5.0	2.9	1.5	5.0
February 12	7.6	7.5	1.7	4.1
March 9	5.6	6.4	------------	------------
March 21	6.7	7.3	------------	------------
April 3	------------	------------	1.7	4.2
April 11	------------	------------	13.2	------------
April 13	------------	------------	12.4	10.8
April 15	------------	------------	9.9	13.5
April 17	------------	------------	9.1	12.8
April 20	------------	------------	8.9	12.0
April 23	7.1	7.0	------------	11.6
April 25	------------	------------	9.1	11.5
May 2	------------	------------	8.1	11.4
May 13	------------	------------	------------	10.8
May 15	4.0	5.1	6.9	9.2
May 31	2.7	4.1	6.5	9.3
June 8	------------	------------	5.8	9.1
June 13	2.4	3.7	5.2	8.9
July 1	1.9	3.1	4.6	8.4
August 1	1.4	1.8	2.3	6.4
August 27	------------	------------	2.2	5.9
September 26	2.9	1.8	------------	------------
November 1	1.3	1.8	1.7	5.3
December 11	------------	------------	------------	4.8

TABLE 11

TRANSPIRATION USE OF WATER BY BRUSH AT DEVIL CANYON SHAFT PLOT, SAN BERNARDINO

May 1 to August 1, 1929

Period	Number of days	Depth in feet	Use of water: For period, Zone	Use of water: For period, Per foot	Use of water: Rate per 30 days
			In inches	In inches	In inches
May 15–May 31	16	0– 2	0.55	0.28	1.03
May 15–May 31	16	2– 6	.74	.19	1.39
May 15–May 31	16	6–16	.46	.05	.86
May 15–May 31	16	0–16	[1]1.75		3.28
May 31–July 1	31	0– 2	0.34	0.17	0.33
May 31–July 1	31	2– 6	.74	.19	.72
May 31–July 1	31	6–16	2.94	.29	2.84
May 31–July 1	31	0–16	[1]4.02		3.89
July 1–August 1	31	0– 2	0.21	0.11	0.20
July 1–August 1	31	2– 6	.96	.24	.93
July 1–August 1	31	6–16	4.19	.42	4.06
July 1–August 1	31	0–16	5.36		5.19
May 15–August 1	78	0– 2	1.10	0.55	
May 15–August 1	78	2– 6	2.44	.61	
May 15–August 1	78	6–16	7.59	.76	
May 15–August 1	78	0–16	11.13		
May 1–August 1	92	0– 2	1.58	0.79	
May 1–August 1	92	2– 6	3.09	.77	
May 1–August 1	92	6–16	7.99	.80	
May 1–August 1	92	0–16	12.66		

[1] Corrected for drainage.

Season 1929–30.—An inspection of the north tunnel on April 18, 1930, showed that the rainfall previous to that date (totaling 15.46 inches) had penetrated to a depth of thirteen feet. Thus 10.25 inches were stored in the soil, leaving 5.21 inches lost by evaporation and transpiration.

The rainfall beginning April 30th and ending May 7th amounted to 4.58 inches. Assuming that four inches of the rain were effective and that 2.25 inches were required to meet the deficiency of soil moisture in the root zone between thirteen and sixteen feet, about 1.75 inches passed below the root zone. This is substantiated by the fact that the moisture content at the 20-foot level increased from 4.5 per cent to 6.9 per cent, 0.44 inch per foot or 1.76 inches for the four-foot section (sixteen to twenty feet) below the root zone.

Table 12 gives the rainfall data for the 1929–30 season, Table 13 the average soil moisture content, and the transpiration use of water by brush during the summer is given in Table 14. Plate VI shows the variation in moisture content of soil at different depths.

TABLE 12

RAINFALL RECORD, 1929-30, DEVIL CANYON SHAFT, SAN BERNARDINO

Date	Rainfall in inches	Date	Rainfall in inches
1929— September 17	0.70	1930— March 31	0.75
1930— January 5- 8	0.75	April 20	0.34
January 9-13	4.05	April 21	.52
January 14-15	1.89	April 29-30	1.43
January 18	.07	May 1-2	.80
January 27	.52	May 3	.99
February 20-26	2.22	May 4	.86
March 5	.60	May 6	.16
March 14-19	3.91	May 7	.34
Total			20.90

TABLE 13

AVERAGE MOISTURE CONTENT AT DEVIL CANYON SHAFT, SAN BERNARDINO, 1930

Dates of sampling	Average moisture content of soil			
	0-2 feet	2-6 feet	North tunnel (13-foot level)	West tunnel (20-foot level)
	In per cent	In per cent	In per cent	In per cent
January 9				4.5
January 20	8.5	8.1		
January 22			1.4	4.5
May 13			8.7	5.6
May 15	6.0[1]	6.0[1]	9.2	6.1
May 20			7.3	6.4
May 28			5.6	6.8
June 6				6.9
June 21	2.6	4.3		6.4
July 23	1.5	2.4	3.0	6.1
August 20	1.3	1.9	2.0	5.9

[1] Estimated.

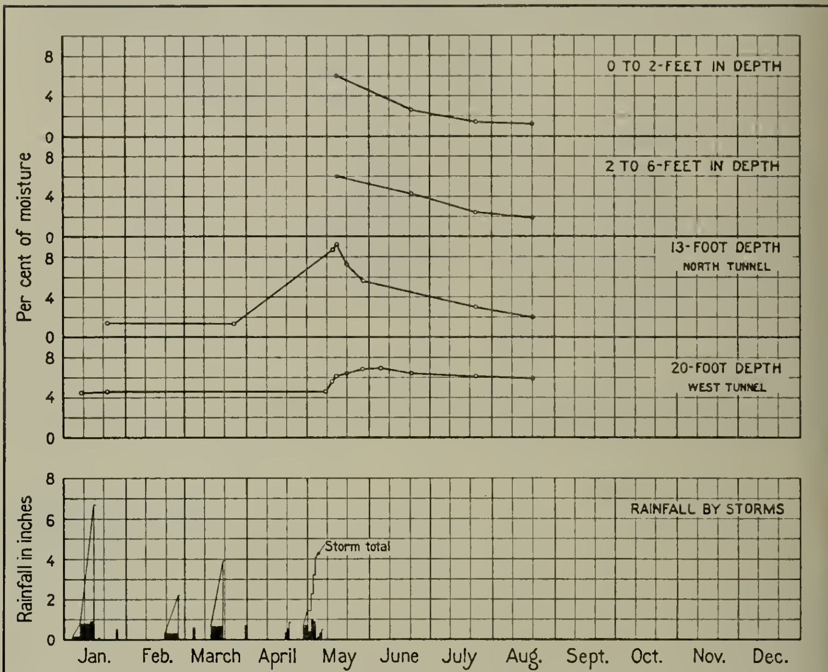
TABLE 14

TRANSPIRATION USE OF WATER BY BRUSH AT DEVIL CANYON SHAFT PLOT, SAN BERNARDINO

May 15 to August 23, 1930

Period	Number of days	Depth in feet	Use of water: For period, Zone	Use of water: For period, Per foot	Use of water: Rate per 30 days
			In inches	In inches	In inches
May 15-June 21	37	0- 2	1.44	0.72	1.17
May 15-June 21	37	2- 6	1.25	.31	1.01
May 15-June 21	37	6-16	3.12	.31	2.53
May 15-June 21	37	0-16	5.81		4.71
June 21-July 23	32	0- 2	0.46	0.23	0.43
June 21-July 23	32	2- 6	1.40	.35	1.31
June 21-July 23	32	6-16	2.70	.27	2.53
June 21-July 23	32	0-16	4.56		4.27
July 23-August 20	28	0- 2	----		
July 23-August 20	28	2- 6	0.37	0.09	
July 23-August 20	28	6-16	1.82	.18	
July 23-August 20	28	0-16	2.19		
May 15-August 23	97	0- 2	1.90	0.95	
May 15-August 23	97	2- 6	3.02	.76	
May 15-August 23	97	6-16	7.64	.76	
May 15-August 23	97	0-16	12.56		

PLATE VI



VARIATION IN MOISTURE CONTENT AT DEVIL CANYON PLOT, 1930.

Muscoy Plots.

The Muscoy brush plots, I and J, are located near Cajon boulevard about five miles northwest of San Bernardino. The growth is medium brush, chiefly chamisal and wild olive, with almost no grass. Plate VII shows the type of brush cover. The soil to a depth of eighteen feet is a coarse Hanford gravelly sand having an apparent specific gravity of 1.60. Table 15 gives the field capacity, initial fall moisture content and initial deficiency below field capacity for various depths in the two plots. The disposal of rain and winter evaporation and transpiration rates are presented in Tables 16, 17, 18 and 19. These results are based on soil samples taken during 1928, 1929 and 1930. Four points of sampling are located on each plot. During this period there was no percolation below the root zone at Plot I. At Plot J there was none during the 1927–28 season, and only 0.6 inch or less during that of 1928–29.

Claremont Tunnel Plot I.

The Claremont brush plot with tunnel is located four miles northwest of Ontario. The tunnel was driven in 20 feet from the side of a gravel pit with the roof of the tunnel 22 feet below the ground surface. Work is carried on here in a manner similar to that employed at Devil Canyon, except that it is on a less extensive scale.

PLATE VII

MUSCOY BRUSH PLOT J. AUGUST, 1930.

TABLE 15

FIELD CAPACITY, INITIAL FALL MOISTURE AND INITIAL DEFICIENCY AT VARIOUS DEPTHS IN MUSCOY BRUSH PLOTS I AND J

Plot	Depth in feet	Field capacity in per cent	Initial fall moisture content in per cent	Initial deficiency below field capacity (total to depth) in inches
Plot I	0–3	4.67	0.8	2.23
	3–6	4.00	1.6	3.61
	6–9	4.00	1.7	4.94
	9–12	4.00	1.7	6.26
	12–15	4.00	1.6	7.64
	15–18	4.00	1.6	9.03
Plot J	0–3	5.50	0.9	2.65
	3–6	4.00	1.2	4.26
	6–9	4.00	1.5	5.70
	9–12	4.00	2.1	6.80
	12–15	4.00	2.6	7.60
	15–18	4.00	3.2	8.07

TABLE 16

DISPOSAL OF RAINFALL AT MUSCOY BRUSH PLOT I, 1927 TO 1930

Date of soil sampling	Amount of rain since last date of sampling in inches	Gain in soil moisture since last date of sampling in inches	Amount of rain and stored soil moisture lost by evaporation-transpiration since last date of sampling in inches	Total rain to date in inches	Total amount of rain stored in soil in inches	Total amount of rain lost by evaporation-transpiration in inches	Soil moisture deficiency in top eighteen feet of soil in inches	Penetration of rain below root zone in inches
Season 1927-28—								
Initial moisture deficiency	--------	--------	--------	--------	--------	--------	9.03	--------
February 8	--------	--------	--------	12.84	5.79	7.05	3.24	0.00
April 26	3.70	—4.23	7.93	16.54	1.56	14.98	7.47	0.00
Season 1928-29—								
October 10	--------	--------	--------	0.00	0.00	--------	9.03	--------
December 27	4.99	+2.32	2.67	4.99	2.32	2.67	6.71	0.00
February 8	5.17	+3.32	1.85	10.16	5.64	4.52	3.39	0.00
May 15	6.17	—3.22	9.39	16.33	2.42	13.91	6.61	0.00
Season 1929-30—								
Initial moisture deficiency	--------	--------	--------	--------	--------	--------	9.03	--------
September 25	--------	--------	--------	0.70	0.29	0.41	8.74	0.00
January 30	7.28	+5.79	1.49	7.98	6.08	1.90	2.95	0.00

TABLE 17

DISPOSAL OF RAINFALL AT MUSCOY BRUSH PLOT J, 1927 TO 1930

Date of soil sampling	Amount of rain since last date of sampling in inches	Gain in soil moisture since last date of sampling in inches	Amount of rain and stored soil moisture lost by evaporation-transpiration since last date of sampling in inches	Total rain to date in inches	Total amount of rain stored in soil in inches	Total amount of rain lost by evaporation-transpiration in inches	Soil moisture deficiency in top eighteen feet of soil in inches	Penetration of rain below eighteen-foot level in inches
Season 1927-28—								
Initial moisture deficiency	--------	--------	--------	--------	--------	--------	8.07	--------
February 8	--------	--------	--------	13.21	5.92	7.29	2.15	0.00
April 26	4.13	—2.80	6.93	17.34	3.12	14.22	4.95	0.00
Season 1928-29—								
October 10	--------	--------	--------	0.00	0.00	--------	8.07	--------
December 27	5.34	+3.62	1.72	5.34	3.62	1.72	4.45	0.00
February 8	6.04	+5.05	0.99	11.38	8.67	2.71	0.00	0.60
May 15	6.81	—3.83	10.64	18.19	4.84	13.35	3.23	0.00
Season 1929-30—								
Initial moisture deficiency	--------	--------	--------	--------	--------	--------	8.07	--------
September 25	--------	--------	--------	0.68	0.29	0.39	7.78	0.00
January 30	7.67	+8.06	--------	8.35	8.35	0.00	0 00	0.28

TABLE 18

WINTER EVAPORATION-TRANSPIRATION RATES AT MUSCOY BRUSH PLOT I, 1927-1930

Period	Number of days in period	Amount of rain during period in inches	Amount of rain stored in the soil at end of period in inches	Evaporation-transpiration during period in inches	Rate of evaporation-transpiration during period in inches per 30 days	Average rate of evaporation-transpiration during rainy season in inches per 30 days
Season 1927-28—						
October 25–February 8	106	12.84	5.79	7.05	2.00	------------
February 8–April 26	78	3.70	1.56	7.93	3.05	------------
October 25–April 26	184	16.54	1.56	14.98	------------	2.44
Season 1928-29—						
October 12–December 27	76	4.99	2.32	2.67	1.05	------------
December 27–February 8	43	5.17	5.64	1.85	1.29	------------
February 8–May 15	96	6.17	2.42	9.39	2.93	------------
October 12–May 15	215	16.33	2.42	13.91	------------	1.94
Season 1929-30—						
January 5–January 30	25	7.28	6.08	1.20	1.44	------------

TABLE 19

WINTER EVAPORATION-TRANSPIRATION RATES AT MUSCOY BRUSH PLOT J, 1927-1929

Period	Number of days in period	Amount of rain during period in inches	Amount of rain stored in the soil at end of period in inches	Evaporation-transpiration during period in inches	Rate of evaporation-transpiration during period in inches per 30 days	Average rate of evaporation-transpiration during rainy season in inches per 30 days
Season 1927-28—						
October 25–February 8	106	13.21	5.92	7.29	2.06	------------
February 8–April 26	78	4.13	3.12	6.93	2.67	------------
October 25–April 26	184	17.34	3.12	14.22	------------	2.32
Season 1928-29—						
October 12–December 27	76	5.34	3.62	1.72	0.68	------------
December 27—February 8	43	6.04	8.67	0.99	0.69	------------
February 8–May 15	96	6.81	4.84	10.64	3.32	------------
October 12–May 15	215	18.19	4.84	13.35	------------	1.86

Over the tunnel there is a medium thin growth of brush (wild olive and sage) growing from two to three feet high, with a fair grass sod. Plate VIII shows the brush cover and soil profile. The soil types are sandy loam and rock, 0–2 feet, and sand-rock and gravel, 2–22 feet.

During the three seasons 1927–28, 1928–29 and 1929–30 all of the rain was held within the root zone and transpired or evaporated. The consumptive use therefore was equal to the rainfall each season, as follows:

Season	*Rain*	*Consumptive use*
1927–28	14.93 inches	14.93 inches
1928–29	12.66 inches	12.66 inches
1929–30	16.35 inches	16.35 inches

PLATE VIII

CLAREMONT TUNNEL PLOT. AUGUST, 1930.

A. Cover Crop. B. Soil Profile.

It is evident from the data for the season of 1929–30, given in Table 20, that at this location not less than 20 inches of rain would be required before deep penetration below the root zone would occur.

The average rate of evaporation-transpiration from January 5 to June 3, 1930, was at the rate of 2.8 inches per 30 days. Table 20 gives typical results of soil sampling.

In May, 1930, a steam shovel was working through a section 500 feet north of the plot. The entire face of the cut, which was 40 feet deep, was moist and the samples taken May 14, 1930, from a depth of 32.5 feet are representative of field capacity. The total rain to this date was 16.12 inches and apparently deep penetration had occurred in this area. The overlying cover of brush had been kept partially removed where the shovel was working.

TABLE 20

AVERAGE MOISTURE CONTENT AT CLAREMONT TUNNEL BRUSH PLOT I, 1929 AND 1930

Depth of sample in feet	Average moisture content of soil									
	October 9, 1929		February 1, 1930				May 31, 1930		June 3, 1930	
	SP	LP	SP	LP	SPs	LPs	P	Ps	P	Ps
1	3.4		10.4	2.8	12.6	12.0			6.3	7.0
2	1.2		3.4	2.4	4.7	8.5			1.9	4.1
3	1.1	0.7	3.4	5.4	5.9	2.1			1.9	4.8
4									1.8	3.0
5									3.8	5.1
6									4.7	7.1
7									2.9	3.8
7.8			4.3	2.8	7.7	9.9				
8			Penetra	tion 8.3	feet				2.6	3.9
8.7			2.9	1.8	4.2	7.0				
9									2.4	4.0
10									1.7	3.2
10.5									1.8	3.1
11									1.7	3.0
11.5									1.8	3.1
12									1.7	2.8
12.5									4.3	4.3
13									1.5	2.1
14									1.4	2.3
15									1.9	3.1
15.5									1.7	2.8
16									1.8	3.3
17									1.8	3.8
18										
19							2.4	3.4		
20							1.8	3.5		
21							1.2	3.2		

NOTE: S=small sample of from 200 to 400 grams. L=large sample of from 2000 to 4000 grams. P=per cent of moisture content based on oven-dry weight of entire sample. Ps=per cent of moisture content based on oven-dry weight of soil in sample.

REMARKS: At 22 feet in roof of tunnel, January 20, 1928, the per cent of moisture in soil was SP 2.3 and LP 2.7. At 32.5 feet below the surface in an area 500 feet north of tunnel, the average moisture content on May 14, 1930, was SP 3.7 per cent and SPs 6.1 per cent.

Palmer Canyon Plot K.

The Palmer Canyon brush plot is located eight miles north of Ontario at an elevation of 1800 feet. The soil is classified in the Placentia series and is a compact red clay loam to a depth of four feet, grading into a coarser sandy loam at seven feet. The cover is a dense mass of weeds, grass, and brush not over two feet high at the points of sampling. Plate IX shows the brush cover and soil profile.

PLATE IX

PALMER CANYON BRUSH PLOT. AUGUST, 1930.
A. Cover Crop. B. Soil Profile.

The total rainfall for the period from January 5 to June 9, 1930, was 19.08 inches. The amount stored in the soil on June 9 was 3.23 inches. Since there was no run-off from the plot, the evaporation and transpiration losses for that period amounted to 15.85 inches, occurring at an average rate of 3.07 acre-inches per acre per 30 days.

In a season when the rains are widely distributed from October 1 to May 1, this plot would have a capacity for 30 acre-inches per acre per year consumptive use without any deep penetration below the root zone.

Table 21 shows field capacity, initial fall moisture content and initial deficiency at various depths. Table 22 gives a summary of moisture percentages for 1929-30.

TABLE 21

FIELD CAPACITY, INITIAL FALL MOISTURE CONTENT AND INITIAL DEFICIENCY AT VARIOUS DEPTHS IN PALMER CANYON BRUSH PLOT K

Depths of zone in feet	Field capacity in per cent	Initial fall moisture content in per cent	Total initial deficiency below field capacity for entire depth to bottom of zone in inches
0-1	18.0	3.7	2.75
1-2	19.0	7.0	5.05
2-3	18.0	10.1	6.57
3-4	15.5	8.6	7.89
4-5	14.5	7.6	9.22
5-6	11.0	6.6	10.06

TABLE 22

AVERAGE MOISTURE CONTENT AT PALMER CANYON BRUSH PLOT K

Depths of zone in feet	Average moisture content of soil				
	Date of sampling				
	October 1, 1929	January 24, 1930	February 4, 1930	March 28, 1930	June 9, 1930
	In per cent	In per cent	In per cent	In per cent	In per cent
0-0.5			20.2	11.1	4.4
0.5-1	3.7		16.1	12.4	5.7
1 - 2	7.0		19.0	17.9	9.7
2 - 3	10.1		17.8	18.2	12.4
3 - 4	8.6		14.8	15.5	12.6
4 - 5			7.6	14.4	11.6
5 - 6			6.6	10.8	9.1
6 - 7				9.3	9.2
7 - 8				6.6	7.6
8 - 9				8.5	8.2
9 -10				9.6	7.2
Average penetration in feet		4.1	4.3	6.1	

Special Plots.

A very favorable opportunity for the study of the disposal of rain in the rocky brush covered areas was presented in January, 1930. A rain extending from January 5 to January 15 fell on dry soil and penetrated to depths below six feet. It was possible then, with the known rainfall and the observed depths of penetration, to compute the initial fall deficiency in moisture content below field capacity.

Plots had been established at seven points on the rocky brush covered fans extending from San Antonio Creek eastward to Day Creek. In October, 1929, each plot was sampled to a depth of three feet. The plots were sampled again in February, 1930, from eighteen to twenty-eight days after the rainfall of January 5 to 15. The samples in February were obtained from dug pits two feet wide by five feet long, excavated to depths below the line of rainfall penetration. Rainfall records for the storm period are given in Table 23. There was no surface run-off at any of these locations during this storm. The evaporation from a free water surface from a Class A Weather Bureau type of pan located at Ontario is given below. The values are for the 24-hour period ending at 7:00 a.m. on the date given.

Date, 1930	Evaporation in inches	Date, 1930	Evaporation in inches
January 6	0.03	January 12	0.03
January 7	.01	January 13	.02
January 8	.03	January 14	.01
January 9	.04	January 15	.02
January 10	.02	January 16	.00
January 11	.02		
Total, January 6–16			0.23

TABLE 23

COMPARISON OF RAINFALL AT NINE FOOTHILL STATIONS FOR STORM OF JANUARY 5 TO 15, 1930

Observer	Location	Elevation above sea level in feet	Storm total in inches
Forbes	Palmer Canyon Road	1,700	7.04
Johnson	San Antonio avenue	1,750	7.28
Norris	East Twenty-fifth street, San Antonio Heights	2,050	7.19
Lewis	North end of Cornelian avenue	2,250	6.99
Parsons	Hellman avenue	1,700	6.95
Reed	Hellman avenue	1,650	7.56
Cherbak	Hermosa avenue	1,850	7.36
Smith	Hermosa avenue	1,350	7.15
Barnes	Etiwanda avenue	1,450	7.61
Average			7.24

The free water loss from a Class A Weather Bureau type of pan is shown to be 0.23 inch for the ten-day storm period. The evaporation loss from the rain storm was therefore set at 0.20 inch and the remainder considered as effective in replenishing the storage in the soil. There was no surface run-off during this storm at any of these plots.

The depths of major root activity are considered to be ten feet for the more compact red sandy loams and sixteen feet for the looser sands and sandy loams. The results from the seven plots are summarized in Table 24.

Plot B2.—The soil classification is Hanford stony sandy loam. The rocks are two inches or less in diameter down to a depth of three feet. Below three feet there are many rocks from three to ten inches in diameter, with a few from fifteen to twenty inches in diameter. The brush cover, consisting mainly of chamisal, is moderately dense, ranging in height from one to three feet.

TABLE 24

PENETRATION OF RAIN AND FALL DEFICIENCY IN SOIL MOISTURE CONTENT AT SEVEN LOCATIONS ON THE ROCKY BRUSH COVERED FANS OF SAN ANTONIO, CUCAMONGA, DEER AND DAY CREEKS

Plot number	Total rain in storm of January 5 to 15, 1930, in inches	Penetration in feet	Fall deficiency in moisture content per foot in inches	Depth considered in feet	Total deficiency in moisture content in inches
B 2	7.28	10.2	0.69	16	11.1
B 3	7.19	7.0	1.00	10	10.0
B 4	7.16	9.6	.75	16	11.9
B 5	7.28	Below 8.0	.50	16	8.0
B 6	7.61	8.5	.87	16	14.0
B 7	6.99	6.0	1.13	10	11.3
B 8	7.36	10.3	.70	16	11.1
Average					11.1

For the top 10.2 feet of soil, the average storage of rain equals 7.08÷10.2=0.69 inch per foot of soil. The fall moisture content therefore has an equivalent deficiency of 11.1 inches in sixteen feet of soil.

Plot B3.—The soil classification is Hanford gravelly sandy loam. It is a semicompact soil and there are not many large rocks. The brush cover is moderately dense, averaging about three feet high. There was a good growth of green grass, two or three inches high, under the brush on February 4, 1930.

For the top seven feet of soil, the average storage of rain equals 6.99÷7.0=1 inch per foot of soil. The fall moisture content therefore has an equivalent deficiency of ten inches in ten feet of soil.

Plot B4.—The soil classification is Tujunga stony sand. There are very few rocks to a depth of 3.5 feet. From 3.5 to 7.7 feet the rock content is high, but from 7.7 to 10.0 feet the profile shows mostly sand. In October, 1929, there was a medium growth of brush ranging from 2.5 to 10.0 feet high, but this was burned off so that in February, 1930, the surface was clean.

For the top 9.6 feet of soil, the average storage of rain equals 7.16÷9.6=0.75 inch per foot of soil. The fall moisture content therefore has an equivalent deficiency equal to 11.9 inches in sixteen feet of soil.

Plot B5.—The soil classification is Tujunga stony sand. The top foot is of relatively fine material, but from two to eight feet the profile shows coarse gravelly sand with many rocks and boulders up to 24 inches in diameter. There is a fairly dense growth of scrub oak, ten feet high, at this location.

For the top eight feet of soil, the average storage of rain equals 0.5 inch per foot of soil. The fall moisture content therefore has an equivalent deficiency equal to eight inches in the top sixteen feet of soil.

Plot B6.—The soil classification is Hanford stony sandy loam. The top two feet are gravelly; the third foot has many rocks from two to eight inches in diameter; and from four to nine feet the profile shows coarse sand and rock. There is a fair growth of brush, mostly wild olive about two feet high.

For the top 8.5 feet of soil, the average storage of rain equals 7.41÷8.5=0.87 inch per foot of soil. The fall moisture content therefore has an equivalent deficiency equal to fourteen inches for sixteen feet of soil.

Plot B7.—The soil classification is Hanford gravelly sandy loam. It is a coarse sandy loam with relatively few rocks to a depth of 6.5 feet. The brush cover is quite dense and is from two to three feet high.

For the top six feet of soil, the average storage of rain equals 6.79÷6.0=1.13 inches per foot of soil. The fall moisture content therefore has an equivalent deficiency equal to 11.3 inches in ten feet of soil.

Plot B8.—The soil classification is Hanford stony sandy loam. Over 50 per cent of the material, by volume, is rock ranging from six inches to two feet in diameter. One rock 3.5 feet in diameter was removed in excavating the hole. The brush cover is dense and is mainly chamisal from three to four feet high.

For the top 10.3 feet of soil, the average storage of rain equals 7.16÷10.3=0.70 inch per foot of soil. The fall moisture content therefore has an equivalent deficiency equal to 11.1 inches for sixteen feet of soil.

General Stations.

No. 75.—The soil is classified as Hanford gravelly sand. The plot is located seven miles northwest of San Bernardino. The brush cover is four feet high and quite dense, and consists mainly of chamisal, wild olive and sage brush.

TABLE 25

RESULTS OF SOIL SAMPLING AT GENERAL STATION No. 75—BRUSH

1928 and 1929

Depth of sample in feet	Average moisture content of soil						
	Season of 1927-28			Season of 1928-29			
	January 26, 1928	April 27, 1928	June 30, 1928	September 25, 1928	December 27, 1928	May 15, 1929	June 30, 1929
	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent
0- 1	8.7	1.7	----------	1.1	8.6	2.7	----------
1- 2	3.3	3.0	----------	1.7	6.6	2.7	----------
2- 3	2.5	1.4	----------	0.6	3.5	1.9	----------
3- 4	2.6	----------	----------	----------	1.0	----------	----------
4- 5	1.8	----------	----------	----------	0.9	2.9	----------
5- 6	1.8	----------	----------	----------	0.7	2.2	----------
6- 7	1.1	----------	----------	----------	----------	3.1	----------
7- 8	1.2	----------	----------	----------	----------	2.9	----------
8- 9	2.1	----------	----------	----------	----------	2.1	----------
9-10	1.0	----------	----------	----------	----------	1.5	----------
10-11	2.0	----------	----------	----------	----------	1.1	----------
11-12	1.9	----------	----------	----------	----------	0.8	----------
12-13	----------	----------	----------	----------	----------	1.0	----------
Depth of penetration in feet	3.8	----------	----------	----------	2.3	8.0	----------
Seasonal rain to date in inches	9.33	16.54	17.67	0.0	4.99	16.33	16.50

There was no penetration of rain below the root zone during the seasons of 1927–28 and 1928–29. The maximum depth of penetration was eight feet, noted in May, 1929. There was no run-off.

During the two seasons of 1927–28 and 1928–29, all of the rain was held within the root zone and transpired or evaporated. The consumptive use of water was therefore equal to the seasonal rainfall, which amounted to 17.67 inches in 1927–28 and 16.50 inches in 1928–29. Table 25 gives the results of soil moisture determinations.

No. 76.—This station is located five miles northwest of San Bernardino. The soil is classified in the Hanford series. It is a coarse, sandy, gravelly loam to a depth of three feet and then gravelly sand to fifteen feet. The cover consists of a scattered growth of chamisal and wild olive from twelve to eighteen inches high, and a fair sod of grass.

There was no penetration of rain below the third foot in either of the seasons of 1927–28 or 1928–29. Due to the seasonal distribution of the storms, the rains were transpired or evaporated shortly after they fell and there was no cumulative storage of rain. The season of 1929–30 was more favorable for deep penetration and the rains had penetrated to a depth of 12.5 feet by April 18, 1930. Soil moisture records are given in Table 26. No run-off occurred from the plot during the last three years. Winter rates of evaporation and transpiration were as follows:

Date	Period	Amount of rain stored in soil at end of period in inches	Total rain to date in inches	Average rate of evaporation-transpiration for winter season per 30 days in inches
April 27, 1928	October 25, 1927, to April 27, 1928	0.35	16.54	2.63
May 15, 1929	October 12, 1928, to May 15, 1929	0.64	16.33	2.19

TABLE 26

RESULTS OF SOIL SAMPLING AT GENERAL STATION No. 76—BRUSH

1928, 1929 and 1930

Depth of sample in feet	Average moisture content of soil								
	Season of 1927-28			Season of 1928-29			Season of 1929-30		
	January 26, 1928	April 27, 1928	June 30, 1928	December 27, 1928	May 15, 1929	June 30, 1929	September 26, 1929	April 18, 1930	June 30, 1930
	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent
0– 1	8.6	2.5		7.2	3.0		3.8	Dry	
1– 2	6.2	2.6		3.6	3.5		2.1	Moist	
2– 3	5.5	2.6		2.5	2.7		2.3	Moist	
3– 4	2.1	2.0		2.0	1.8			Moist	
4– 5	1.6			2.2	1.5			Moist	
5– 6	1.9			1.4	1.3			Moist	
6– 7	1.6				1.0			Moist	
7– 8	1.4				1.1			Moist	
8– 9	1.4				1.1			Moist	
9–10	1.5				0.9			Moist	
10–11	1.4				1.0			Moist	
11–12	1.5				0.9			Moist	
12–13	1.4							Dry	
13–14	1.5							Dry	
14–15	1.8							Dry	
Depth of penetration in feet	2.8			1.5				12.5	
Seasonal rain to date in inches	9.33	16.54	17.67	4.99	16.33	16.50	0.70	15.46	20.90

No. 101.—The soil type is Ramona loam and the cover consists of a medium growth of brush about three feet high and a fair sod of grass. The penetration from 11.15 inches of rain to April 18, 1930, was six feet. Below six feet the soil was dry to ten feet and then partly moist to thirteen feet. There was no run-off from the plot.

Summary of the Disposal of Rainfall on Brush Plots.

The results of the last three years work indicate that at least nineteen inches of seasonal rainfall is necessary before any material amount of water will penetrate below the root zone of the brush on the valley floor. A seasonal rainfall of less than nineteen inches is usually consumed by the brush cover before any portion of it reaches the ground water. Table 27 gives a summary of the disposal of rainfall on the brush plots. Table 28 gives a summary of average winter rates of evaporation-transpiration and initial fall deficiency in soil moisture content for brush-covered areas.

TABLE 27

SUMMARY OF DISPOSAL OF RAINFALL ON BRUSH PLOTS, 1927 TO 1930

Location	Season	Rainfall in inches	Evaporation and transpiration in inches	Penetration below root zone in inches
Devil Canyon Shaft	1927–28	[1]32.00	27.00	5.0
	1928–29	[1]24.82	18.82	6.0
	1929–30	20.90	19.10	1.8
Muscoy Plot I	1927–28	17.67	17.67	0.0
	1928–29	16.50	16.50	----------
Muscoy Plot J	1927–28	18.54	18.54	0.0
	1928–29	18.19	17.59	0.6
Claremont	1927–28	14.93	14.93	0.0
	1928–29	12.66	12.66	0.0
	1929–30	16.35	16.35	0.0
Palmer Canyon	1929– 0	19.58	19.58	0.0
Station No. 75	1927–28	17.67	17.67	0.0
	1928–29	16.50	16.50	0.0
Station No. 76	1927–28	17.67	17.67	0.0
	1928–29	16.50	16.50	0.0

[1] Includes artificial rain.

GRASS AND WEEDS

Devil Canyon Plot B.

The Devil Canyon plot B is located one-half mile southeast of the shaft brush Plot A. It offers an opportunity to compare the penetration of rain on brush-covered areas with that on grass and weed land. The soil type is a Hanford gravelly sandy loam. The land was cleared for grain about 1918, but has not been farmed since 1926. Pits were dug for the purpose of soil sampling at the beginning and end of the rainy season and after the major rain storms.

The grass and weed cover on Plot B is relatively thin and the winter rate of evaporation-transpiration is low. The initial fall deficiency in soil moisture content is 6.9 inches, whereas for the shaft brush Plot A it was 12.5 inches.

TABLE 28

SUMMARY OF AVERAGE WINTER RATES OF EVAPORATION-TRANSPIRATION AND INITIAL FALL DEFICIENCIES IN SOIL MOISTURE CONTENT FOR BRUSH COVERED AREAS

Plot	Season	Average winter rate of evaporation-transpiration per 30 days in inches	Initial fall deficiency in moisture content of the soil in inches
Claremont I	1929–30	2.80	----------
Muscoy I	1927–28	2.44	9.0
	1928–29	1.94	----------
Muscoy J	1927–28	2.32	8.1
	1928–29	1.86	----------
Palmer Canyon K	1929–30	3.07	10.1
General Station 76	1927–28	2.63	----------
	1928–29	2.19	----------
Devil Canyon Shaft	1928–29	----------	12.5
Brush, B2	1929–30	----------	11.1
Brush, B3	1929–30	----------	10.0
Brush, B4	1929–30	----------	11.9
Brush, B5	1929–30	----------	8.0
Brush, B6	1929–30	----------	14.0
Brush, B7	1929–30	----------	11.3
Brush, B8	1929–30	----------	11.1
Average	----------	2.40	10.6

Deep penetration below the root zone may be expected on the grass and weed Plot B after from ten to twelve inches of seasonal rain has fallen. This may be compared with a requirement of eighteen to twenty-two inches for the shaft brush Plot A. However, it should be noted again that the winter grass and weed cover on Plot B is thin. Other plots where the soil supports a denser grass and weed cover have shown a consumptive use of from twelve to fifteen inches or more.

The depth of root activity was found to be eight feet. The soil moisture deficiency November 3, 1928, was 6.91 inches. On February 21, 1929, the total rain to date was 10.75 inches, and the soil had been wet to field capacity to eight feet. Some moisture had penetrated below the root zone.

The soil moisture deficiency September 26, 1929, was 6.97 inches. On January 22, 1930, the total rain to date was 7.46 inches, the storage of moisture in the root zone was 5.87 inches, the loss by evaporation was 1.59 inches, and the remaining soil moisture deficiency was 1.10 inches. The results of soil sampling are given in Tables 29 and 30.

Pyle Shaft Plot II.

The Pyle shaft plot II is located seven miles northeast of Ontario on the Deer Creek fan. The soil is classified as Tujunga stony sand. The condition of the grass and weed cover is shown in Plate X. The shaft was dug sixteen and one-half feet deep in January, 1928. A tunnel was extended out ten feet from the shaft with the roof eleven feet below the ground surface. The material at the end of the tunnel was fairly uniform coarse sand with no large rocks such as were found in the top ten feet of soil. Representative samples therefore were obtained readily by boring out laterally from the sides and ends of the tunnel at the thirteen-foot level. The tunnel was kept closed off from the shaft by a trap door.

TABLE 29

AVERAGE MOISTURE CONTENT AT DEVIL CANYON PLOT B—GRASS AND WEEDS

November 3, 1929, to January 22, 1930

Date of sampling	Average moisture content of the soil											
	First foot	Second foot	Third foot	Fourth foot	Fifth foot	Sixth foot	Seventh foot	Eighth foot	Ninth foot	Tenth foot	Eleventh foot	Twelfth foot
	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per ce nt	In per cent
1928—												
November 3	SP 2.2	2.0	1.6	1.1	1.4	1.8	---	---	---	---	---	---
November 3	LP 2.8	2.2	1.6	1.1	1.1	---	---	---	---	---	---	---
1929—												
February 21	SP 8.3	9.8	8.9	7.1	4.7	6.0	4.7	4.2	4.9	5.3	---	---
February 21	LP 9.1	---	8.0	---	5.8	---	4.0	---	---	---	---	---
April 3	SP 7.7	8.2	9.4	6.5	3.6	3.9	3.4	[2]11.8	---	---	---	---
September 26	SP 2.5	2.0	2.5	---	---	---	---	---	---	---	---	---
September 26	LP 2.0	2.3	2.4	---	---	---	---	---	---	---	---	---
1930—												
January 22	SP 9.2	10.5	12.1	8.3	5.6	[1]3.5	2.0	2.4	9.9	5.7	2.6	2.7
January 22	SPs 10.1	11.4	13.3	11.1	9.1	[1]5.5	2.8	3.3	10.9	7.7	3.1	3.9
January 22	LP 9.8	9.7	10.9	5.4	2.7	[1]1.3	1.6	1.6	8.1	4.0	2.4	2.4
January 22	LPs 10.8	11.8	13.5	11.9	11.9	[1]6.1	3.0	3.9	9.4	6.2	3.6	4.4

[1] Average depth of rain penetration=5.75 feet.
[2] Loam.

NOTE: S —Small 200 gram samples (with no large rocks.)
L —Large 4000 gram samples.
P —Per cent of moisture based on oven-dry weight of entire sample.
Ps—Per cent of moisture based on oven-dry weight of soil in sample.

TABLE 30

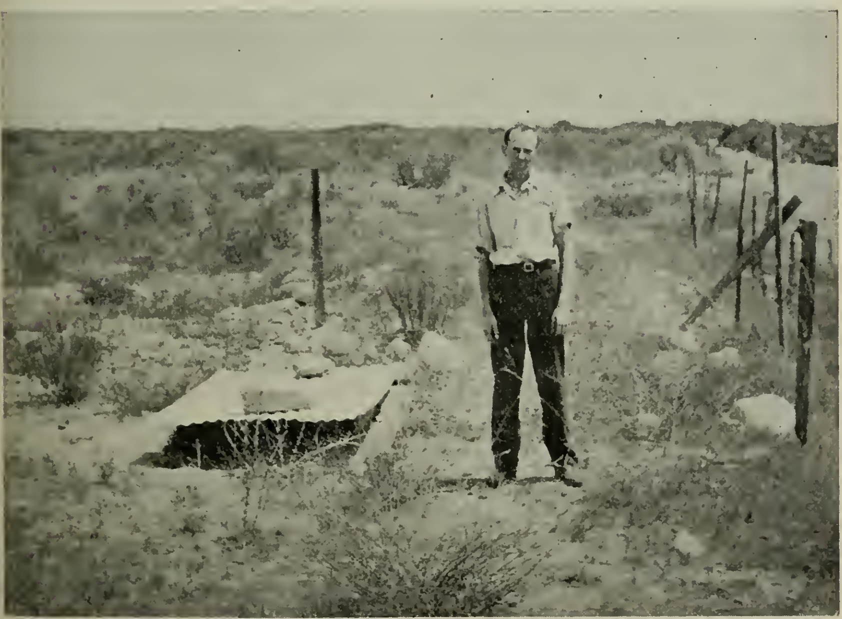
INITIAL DEFICIENCY IN SOIL MOISTURE CONTENT AT BEGINNING OF THE RAINY SEASON, 1928 AND 1929, DEVIL CANYON PLOT B

Depth of sample in feet	Average deficiency of soil moisture			
	November 3, 1928		September 26, 1929	
	Per foot in inches	[1]Total in inches	Per foot in inches	[1]Total in inches
0–1	1.30	1.30	1.44	1.44
1–2	1.40	2.70	1.39	2.83
2–3	1.69	4.39	1.55	4.38
3–4	1.06	5.45	1.00	5.38
4–5	0.46	5.91	0.50	5.88
5–6	0.40	6.31	0.41	6.29
6–7	0.40	6.71	0.34	6.63
7–8	0.20	6.91	0.34	6.97
8–9	0.00	6.91	0.00	6.97

[1] Total deficiency of soil moisture from zero to base of section.

When the shaft was dug, January 2, 1928, the depth of penetration was seven feet. The total seasonal rain on this date was 7.33 inches. Samples also were obtained from dug pits November 8, 1928,

PLATE X



PYLE SHAFT PLOT. AUGUST, 1930.

February 26, 1929, and February 11, 1930. These pits were located ten feet distant from a point directly over the end of the tunnel.

On February 26, 1929, the depth of penetration was 5.4 feet. The total seasonal rain on this date was 9.48 inches.

The depth of major root activity appears to be nine feet as determined from dug pits, the soil being dry to that depth in the fall. A few rootlets were found to extend to a depth of eleven feet.

The amount and distribution of the rains during the 1927–28 and 1928–29 seasons were unfavorable for deep penetration. There was sufficient storage capacity within the root zone to hold the rains after they fell until they were either evaporated or transpired from the grass and weed cover. The seasonal rain for 1927–28 was 15.49 inches, and for 1928–29 the seasonal rain was 13.54 inches.

The concentrated storms of the 1929–30 season caused penetration below the root zone. By February 6, 1930, the seasonal rain totaled 6.87 inches and this was sufficient to wet the soil to below the root zone, as evidenced by the tunnel samples at the thirteen-foot level. The amount of penetration could not be calculated as the soil was so rocky it could not be sampled regularly throughout the depth of the root zone. The 1929–30 seasonal rain amounted to 17.25 inches. Typical results of soil sampling are given in Table 31.

TABLE 31

RESULTS OF SOIL SAMPLING AT PYLE SHAFT PLOT II—GRASS AND WEEDS

1928, 1929 and 1930

Depth of sample in feet	Average moisture content of soil								
	November 8, 1928		February 26, 1929		October 10, 1929	February 11, 1930			
	SP	LP	SP	LP	SP	SP	LP	SPs	LPs
	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent
1	0.7	1.4	5.0	3.0	0.9	5.4	4.3	6.1	6.4
2	1.0	0.9	3.1	----	0.7	3.0	2.1	4.7	5.8
3	1.4	0.8	2.9	2.1	0.6	6.9	2.2	7.3	6.1
4	1.9	1.3	4.4	----	----	----	----	----	----
5	----	----	2.5	1.5	----	----	----	----	----
			(Penetra	tion 5.4 ft.)					
6	1.2	1.2	1.6	----	----	----	----	----	----
7	1.5	1.1	2.6	2.3	----	----	----	----	----
8	----	----	2.9	----	----	6.2	3.8	9.4	11.5
9	2.5	1.9	----	----	----	6.5	4.2	8.3	11.2
10	2.2	1.9	----	----	----	----	----	----	----
13-foot level in tunnel	January 9, 1928	April 11, 1928	April 17, 1929	February 6, 1930	May 7, 1930	May 13, 1930	----	----	----
	SP 4.6	SP 4.0	SP 4.2	SP 6.0	SP 5.2	SP 6.2	----	----	----

NOTE: S=small sample of from 200 to 400 grams. L=large sample of from 2000 to 4000 grams. P=per cent of moisture based on oven-dry weight of entire sample. Ps=per cent of moisture based on oven-dry weight of soil in sample.

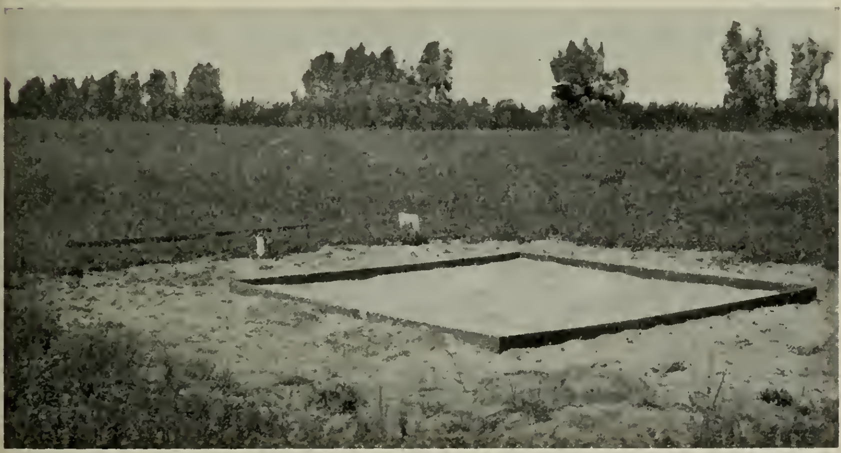
Special Rainfall Penetration Stations.

During the 1927–28 rainy season, special rainfall penetration stations for intensive soil sampling were maintained in typical areas. A plot in crop and a clean cultivated plot are adjacent to one another at these stations. The clean cultivated plot is level and should give a maximum penetration, as the losses are by evaporation only. The adjacent plot in crop is on the undisturbed surface of the valley floor and the losses by evaporation, transpiration and run-off should give a minimum penetration.

The stations were equipped with run-off plots and standard rain gauges. The run-off plots were ten by ten feet, bordered with one by twelve inch planks buried on edge in the ground to a depth of eight inches. Plate XI shows typical adjacent plots.

Sets of soil samples were taken at four locations in each plot, in foot sections, to depths of from six to eighteen feet, and the moisture content of each sample was determined. The time interval between soil sampling was governed by the frequency and character of the rain storms. The total area of the soil disturbed on each date of sampling was five square inches, or 0.035 per cent of the plot area of 100 square feet. The soil sampling locations were never closer than one foot from any previous sampling hole, nor were samples ever taken closer than one foot from the border of the plot. Each hole was carefully backfilled with soil tamped in place.

PLATE XI



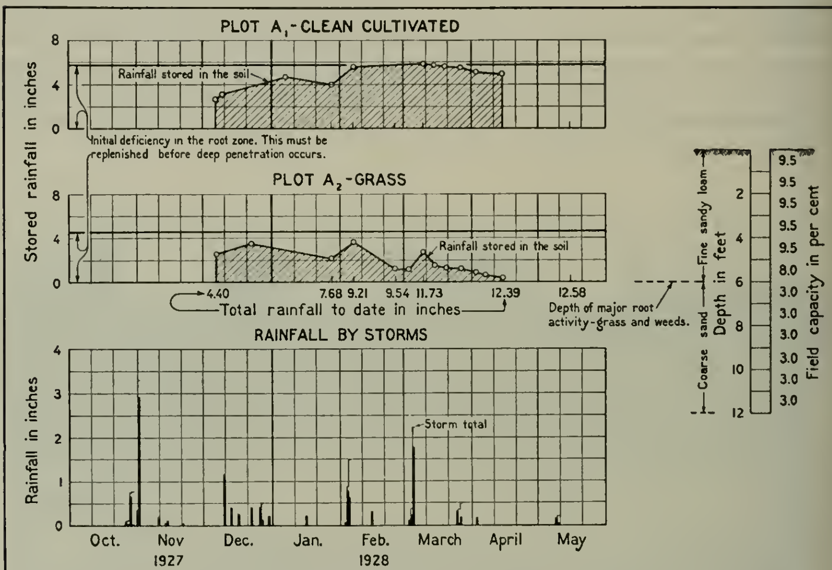
TYPICAL CLEAN CULTIVATED PLOT AND ADJACENT GRASS AND WEED PLOT.

Station A.—This station was located two miles northeast of Anaheim on the property of the Anaheim Union Water Company. The soil is a Hanford fine sandy loam and is typical of a large area in Orange County. No run-off occurred at this station.

Plot A1 was clean cultivated early in December, 1927. The depth of major root activity was six feet and below that the soil was moist. The top six feet of soil is fine sandy loam, with an average field capacity of 9.25 per cent. From six to twelve feet the soil is a coarse sand with a field capacity of three per cent. The initial soil moisture deficiency below field capacity of the entire twelve-foot section was 5.8 inches. Early in February, 1928, the soil was filled to field capacity. A rain storm of 2.19 inches occurred early in March, and about 1.5 inches of rain water penetrated below the root zone. The total rainfall to April 15 was 12.39 inches, of which 4.9 inches were stored in the soil, about 1.5 inches penetrated to the ground water, and six inches were lost mainly by evaporation, although some transpiration occurred prior to the time the plot was clean cultivated in December.

Plot A2 was covered with grass during the winter months. A crop of weeds replaced the grass in May. The characteristics of soil in Plot A2 were the same as Plot A1, with the exception that the initial soil moisture deficiency was 4.6 inches instead of 5.8. The total seasonal rainfall of 12.58 inches was entirely lost by evaporation and transpiration. Plate XII shows the results obtained on Plots A1 and A2 graphically.

PLATE XII



STORAGE OF RAINFALL IN THE SOIL, PLOTS A-1 AND A-2, ANAHEIM UNION WATER COMPANY.

Station D.—Station D is located five miles south of Ontario. The soil in the top four feet is a Hanford sand, grading into a silt loam at eight feet and becoming sandy again in the twelfth foot. During the winter of 1926-27 and summer of 1927, an extremely heavy crop of grass, weeds and sunflowers grew on the plots. The sunflowers were over six feet in height and results parallel heavy brush conditions rather than grass and weeds. The depth of root activity was eleven feet. The deficiency of soil moisture in the top twelve-foot section of each of the plots, D1 and D2, was 13.2 inches. On December 6, 1927, when the plots were started, two inches of moisture were stored in the soil out of a total rainfall of 3.73 inches. Thus 1.73 inches were lost by transpiration and evaporation from October 25 to December 6, 1927. No run-off occurred at this station.

Plot D1 was clean cultivated and at the end of the rainy season 6.8 inches of rain had been stored in the soil. From December 6, 1927, to April 17, 1928, 2.99 inches were lost by evaporation out of a total of 7.79 inches of rainfall during that period.

From December 6, 1927, to April 17, 1928, Plot D2, which was covered with a thin grass crop, showed a consumptive use of 6.19 inches.

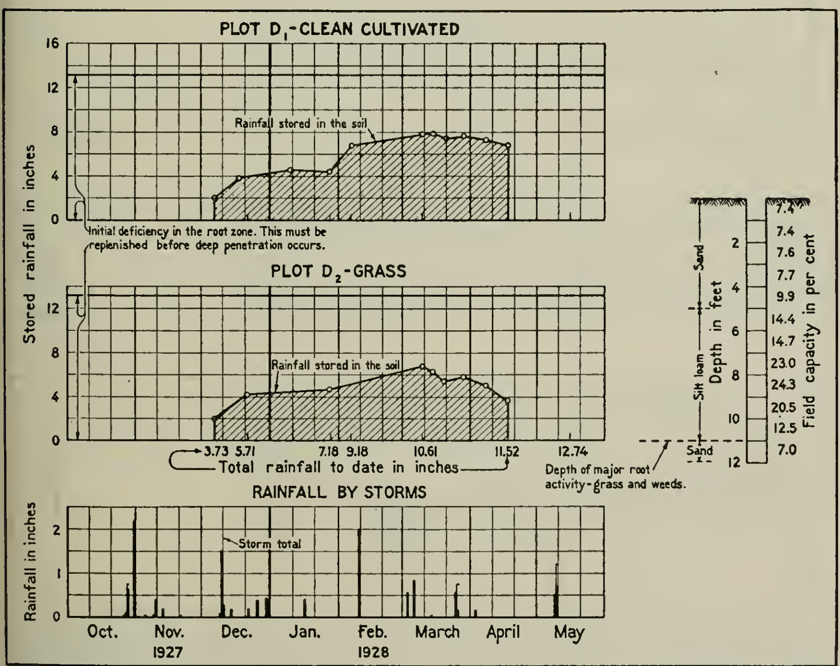
The total rainfall for the 1927-28 season was 12.74 inches. This was all lost by evaporation and transpiration. The results of Plot D1 and D2 for the 1927-28 season are shown in Plate XIII. No rain penetrated below the root zone in either plot.

Station E.—This station is located two miles southeast of Ontario. The soil is classified as a Hanford sand. The depth of major root activity was eleven feet. No run-off occurred at the station.

Plot E1 was clean cultivated and started December 17, 1927. The initial soil moisture deficiency was 7.6 inches. The estimated consumptive use of water from October 27, 1927, to December 17, 1927, was 2.66 inches. From December 17, 1927, to April 17, 1928, 4.1 inches were lost by evaporation. The amount of rain stored in the soil at the end of the rainy season on April 17, 1927, was six inches. There was no penetration below the root zone.

Plot E2 had an initial soil moisture deficiency of six inches. Grass was growing on the plot. Prior to December 17, 1927, the consumptive

PLATE XIII

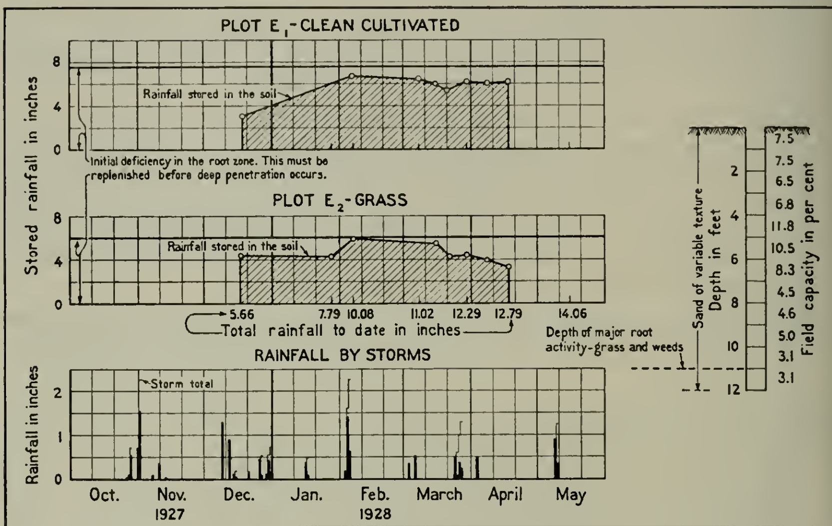


STORAGE OF RAINFALL IN THE SOIL, PLOTS D-1 AND D-2, EDISON AVENUE.

use of water was estimated to be 1.26 inches. The consumptive use of water from December 17, 1927, to April 17, 1928, was 8.33 inches. There was no penetration of rain water below the root zone. The consumptive use of water for 1927–28 was equal to the total seasonal rainfall, or 14.06 inches. Plate XIV graphically shows the results obtained on Plots E1 and E2.

Station F.—This station was located on a Hanford loam soil at Cucamonga. There was no run-off during 1927–28. The usual clean cultivated plot was not established at this station.

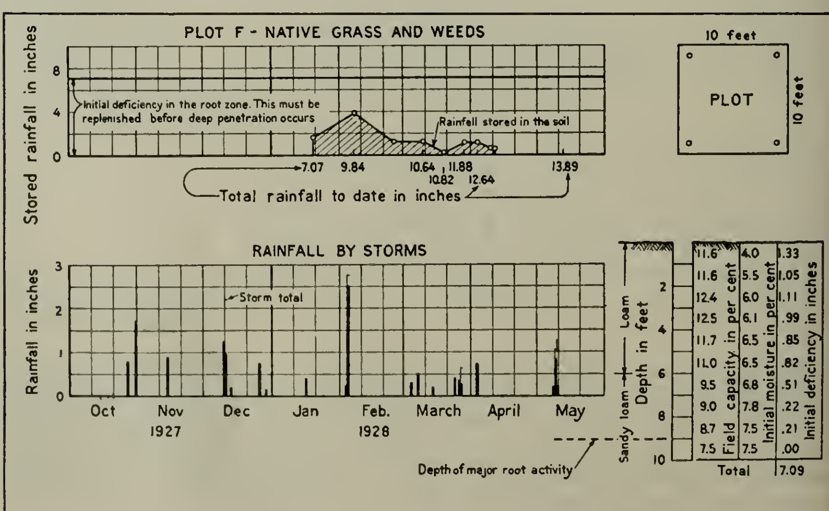
PLATE XIV



STORAGE OF RAINFALL IN THE SOIL, PLOTS E-1 AND E-2, BRAUNDALE ACRES.

The grass and weed plot had an initial soil moisture deficiency of 7.1 inches and the depth of major root activity was nine feet. No rainfall penetrated below the root zone. The consumptive use of water from October 26, 1927, to January 19, 1928, was 5.47 inches, and from January 19, 1928, to April 11, 1928, was 6.67 inches. The consump-

PLATE XV



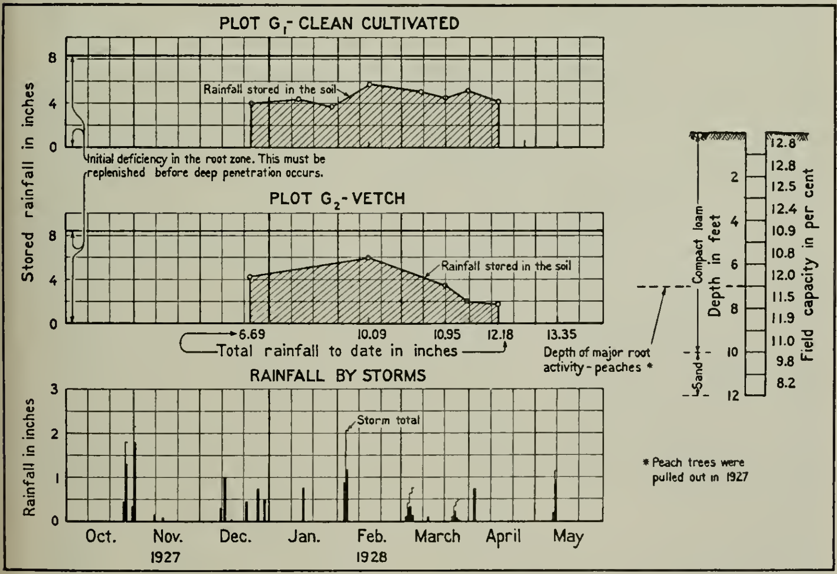
STORAGE OF RAINFALL IN THE SOIL, PLOT F, CUCAMONGA.

tive use of water for 1927-28 was 13.89 inches and included all the rainfall. Plate XV graphically shows the results obtained on Plot F.

Station G.—The location of this station was two miles east of Wineville at Glen Avon Heights. The soil is of a Placentia loam type and very compact. The trees growing on the plots depleted the moisture in the soil to a depth of seven feet, but they were pulled out several months before the rainy season started in 1927. No run-off occurred during 1927-28.

Plot G1 was clean cultivated and had an initial moisture deficiency of 8.2 inches. The consumptive use of water from October 26, 1927, to December 23, 1927, was about 2.8 inches. The evaporation from soil, December 23, 1927, to April 13, 1928, was about 5.3 inches. On April 13, 1928, 4.1 inches of moisture were stored in the soil.

PLATE XVI



STORAGE OF RAINFALL IN THE SOIL, PLOTS G-1 AND G-2, GLEN AVON HEIGHTS.

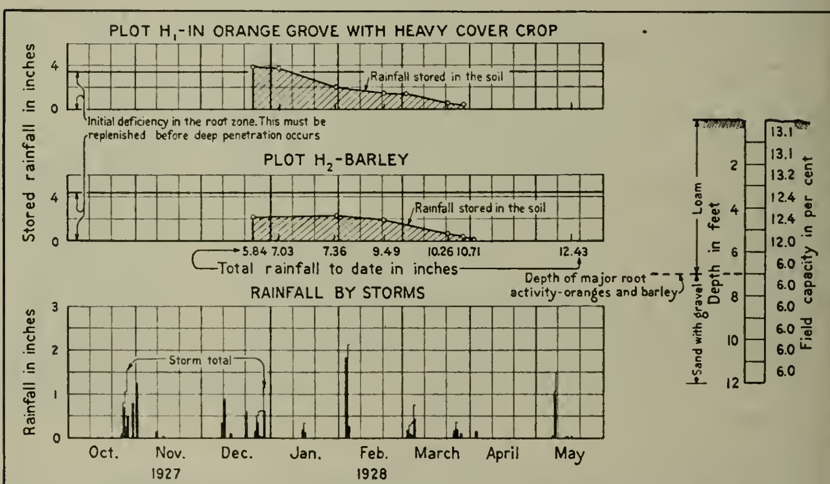
Plot G2 had an initial soil moisture deficiency of 8.5 inches. A crop of vetch was growing on it during the winter. The consumptive use of water from October 26, 1927, to December 23, 1927, was 2.4 inches and from December 23, 1927, to April 13, 1928, was 8.1 inches. The consumptive use for 1927-28 season equalled the rainfall, 13.35 inches. Plate XVI graphically shows the results obtained on Plots G1 and G2.

Station H.—This station was established two miles south of Redlands for the purpose of comparing rainfall penetration on an irrigated orange grove and on a nonirrigated barley field. The soil was a Placentia loam with gravel and sand below six feet. The plots were within 125 feet of each other and the major depth of root activity was five feet in each case.

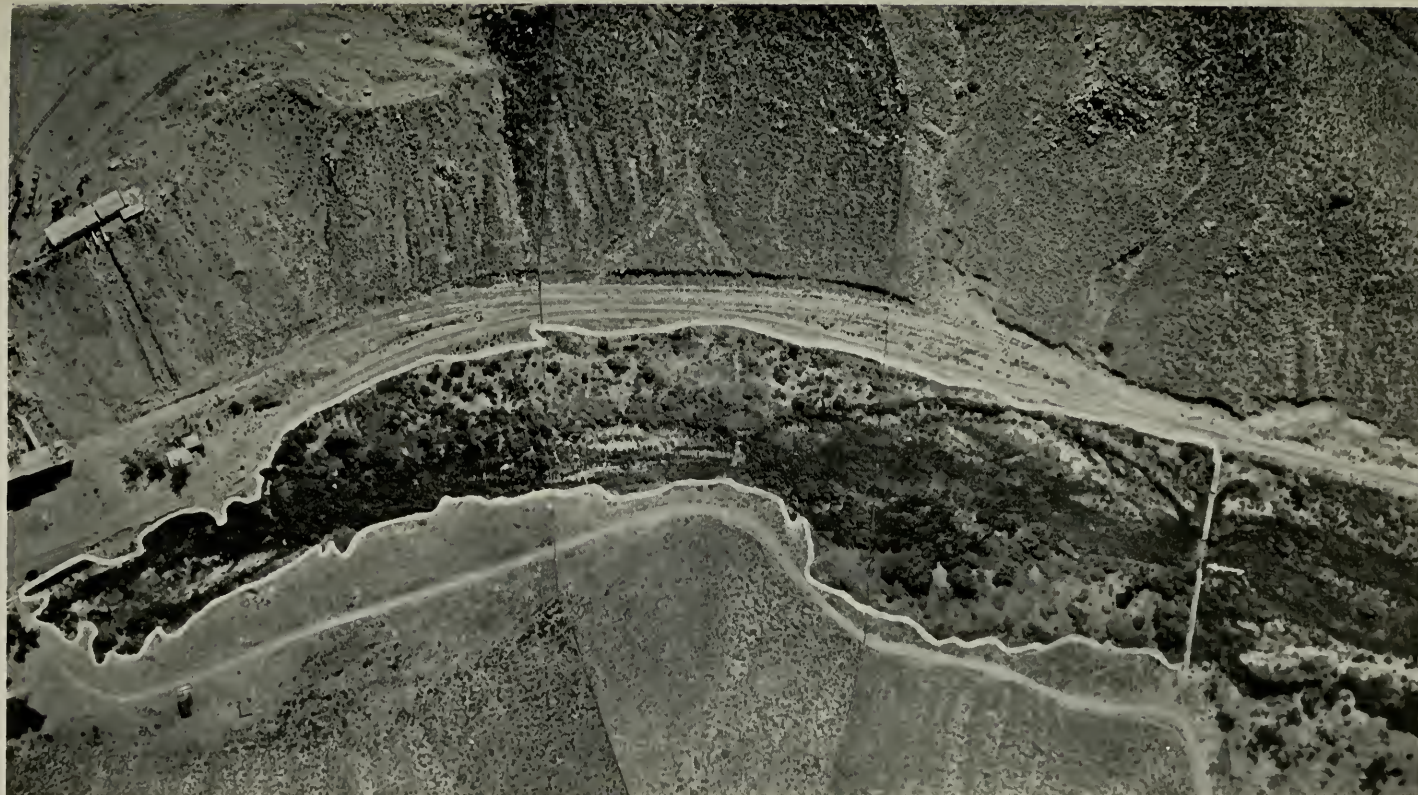
Plot H1 was in an orange grove with a heavy cover-crop. The initial soil moisture deficiency was 3.4 inches. Some rain penetrated below the root zone before January 5, 1928, but after that the moisture in the root zone was used rapidly by the cover crop and no further penetration occurred.

In Plot H2 a barley crop was growing and the initial soil moisture deficiency in the root zone was 4.3 inches. From October 25, 1927, to December 24, 1927, the consumptive use of water was 3.7 inches. During the period December 24, 1927, to April 2, 1928, the consumptive use was 6.8 inches. The rainfall for the season was 12.43 inches and this was entirely lost by evaporation and transpiration since no run-off or deep penetration occurred. Plate XVII graphically shows the results on Plots H1 and H2.

PLATE XVII



STORAGE OF RAINFALL IN THE SOIL, PLOTS H-1 AND H-2, REDLANDS.



TEMESCAL CREEK MAP.

Photographed by United States Army Air Service.

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CHAPTER IV

CONSUMPTIVE USE OF WATER BY NATIVE VEGETATION ALONG STREAM CHANNELS

Measurements on Temescal Creek.

A rather unique opportunity for measuring losses of water by evaporation and transpiration from willows, tules and kindred moist land growths exists on Temescal Creek, four miles southeast of Corona. There are 12.8 acres of moist land on the canyon floor sharply outlined by a railroad grade along the east side and a road grade along the west side. The upstream end of the area is marked by an old, broken rock dam. Water is forced to the surface at this dam and flows on a very flat grade through a gap in the center. The outflow from the area passes under a bridge 2100 feet downstream from the dam, and again is confined to a narrow channel by the fills on each side of the bridge.

There is no evidence of any seepage increment of water reaching the area studied from the rocky hills flanking it on the sides. The winters of 1927–28 and 1928–29 were seasons of scant rainfall and all growth outside the moist area was dry and brown at the time of the test. Even the slight depressions along the rocky hillsides showed no evidence of sub-irrigation. Plate XVIII is an airplane map of the area* made in June, 1929. The moist area as obtained from this map by planimeter measurements was found to be 12.8 acres.

The method adopted for determining the rate of loss due to the moist land growth was to establish the inflow past the dam, the outflow past the bridge and the loss due to underflow. The difference between inflow and the sum of outflow and underflow was charged to evaporation and transpiration losses in the moist area.

Plate XIX A shows the gaging station at the old dam. A six-inch Parshall flume was installed March 30, 1929, with a still well for measuring the upper head. Readings were taken from two to four times a week and a rating curve established for the Geological Survey recorder,† which recorded the water level in the still pool upstream from the flume. Some idea of the rapidity of plant growth at that time of the year may be had from the fact that it was necessary to clean out the tules, water cress and moss, both above and below this station, each week.

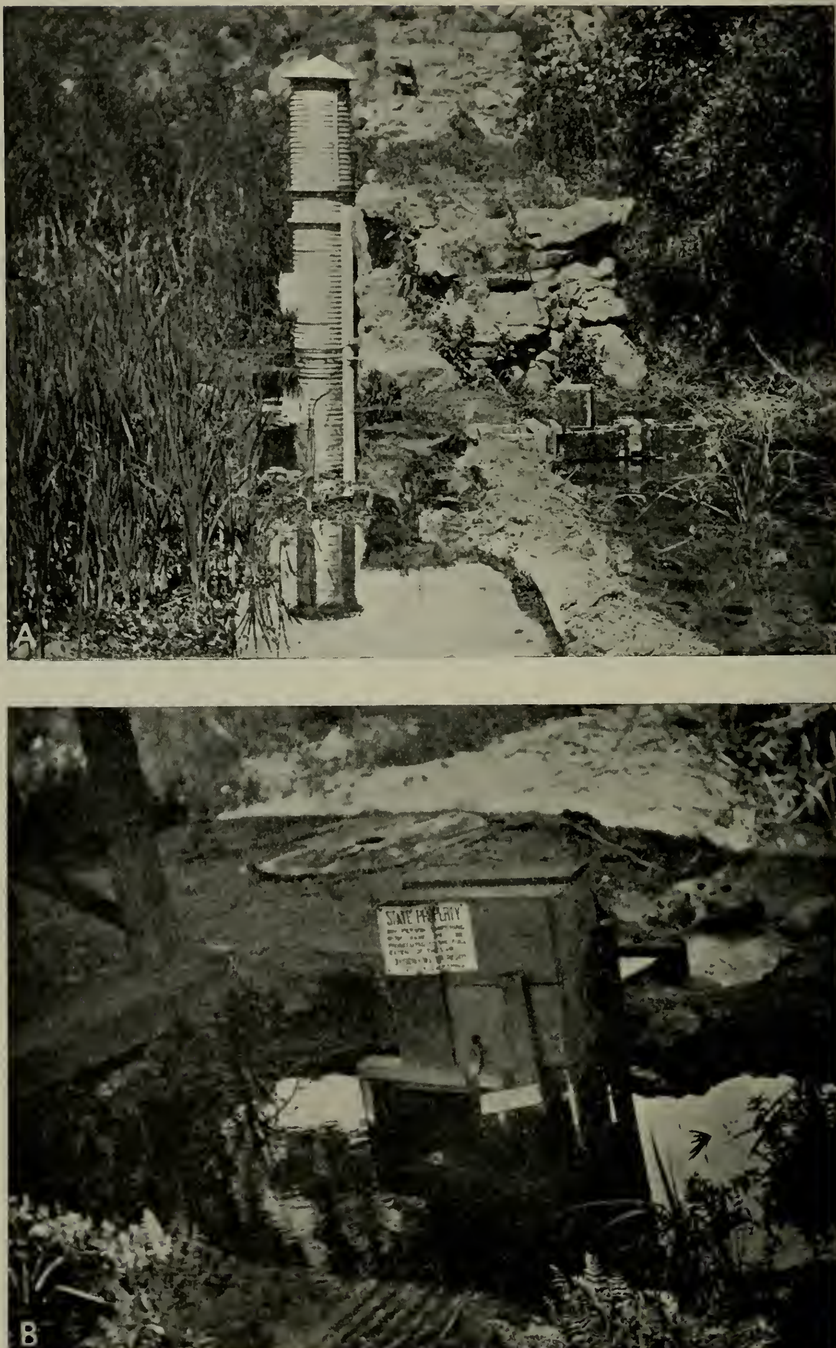
Plate XIX B shows the gaging station at the bridge. A six-inch Parshall flume was installed here on April 2, 1929. A seven-day recorder was installed on this flume to give a continuous record of the upper head. This station was visited twice each week.

The test was started April 15, 1929, and continuous records were made until May 27, 1929, at which time the flow past the bridge dropped below 0.05 second-foot, ceasing entirely on May 29.

* Photo by United States Army Air Service.

† Gage height record furnished by courtesy of F. C. Ebert and H. C. Troxell of the United States Geological Survey.

PLATE XIX



TEMESCAL CREEK GAGING STATIONS.

A. Control at Dam Showing Six-inch Parshall Flume and U. S. Geological Survey Recorder Shelter. B. Control at Bridge Showing Six-inch Parshall Flume and Recorder Shelter.

TABLE 32

DIFFERENCES IN FLOWS OF TEMESCAL CREEK AT TWO-HOUR INTERVALS PAST DAM AND BRIDGE

Date	Flows in second-feet for a. m. hours						Flows in second-feet for p. m. hours						Evaporation in inches	
	2	4	6	8	10	12	2	4	6	8	10	12	Pan[1]	Lake[2]
1929—														
April 15	------	------	------	------	0.140	0.148	0.148	0.148	0.153	0.160	0.159	0.152	0.14	0.094
April 16	0.146	0.146	0.144	0.147	.149	.150	.160	.178	.196	.201	.202	.198	.08	.054
April 17	.188	.174	.167	.157	.151	.150	.152	.162	.175	.190	.192	.180	.16	.107
April 18	.173	.164	.159	.150	.146	.144	.147	.149	.156	.155	.155	.154	.11	.074
April 19	.150	.142	.139	.131	.131	.139	.143	.153	.179	.181	.198	.199	.04	.027
April 20	.180	.167	.158	.150	.150	.154	.168	.182	.193	.197	.194	.192	.04	.027
April 21	.180	.170	.160	.152	.150	.145	.158	.179	.199	.209	.215	.211	.10	.067
April 22	.202	.196	.175	.168	.167	.171	.178	.204	.214	.220	.217	.207	.17	.114
April 23	.201	.196	.190	.188	.190	.210	.212	.226	.230	.234	.227	.218	.17	.114
April 24	.214	.205	.199	.198	.200	.203	.212	.226	.239	.245	.239	.221	.18	.121
April 25	.212	.209	.209	.207	.210	.220	.232	.238	.238	.232	.223	.218	.17	.114

[1] Loss from a Class A Weather Bureau type of pan located at Ontario.
[2] Equivalent loss from a lake surface, being the pan values multiplied by the factor 0.67. Pan readings are for the 24-hour period preceding 7 a. m. on the date given.

The weather remained cloudy and cool, with traces of rain from April 15 to April 20, and this period afforded an opportunity to establish the loss due to underflow. Table 32 gives the differences in flows past the dam and bridge, respectively, at two-hour intervals from April 15 to April 25. The last two columns of this table give the free water surface losses as determined from a Class A Weather Bureau type of pan at Ontario. The indicated loss from a lake surface for each of the 24-hour periods ending at 7 a.m. on April 19 and April 20, respectively, is shown to be 0.027 inch per day. With this indicated loss for the 24-hour period, the rate of loss by evaporation and transpiration during the early morning hours of these two days must necessarily have been extremely low. This affords the basis for determining the loss chargeable to underflow. An inspection of the table shows the minimum differences in flow on these two days to average 0.14 second-foot. This value was also approached on April 15, 16 and 21 as indicated by the boldface values in the table. The loss of water due to underflow therefore was assigned this value—0.14 second-foot—and all remaining differences charged to evaporation and transpiration.

A graphical record of the test is given in Plate XXI. Plate XXI A shows the continuous record of flow past the two control stations from April 15 to May 27. Discharges were computed for each two hours throughout the period and the curves drawn as shown. Plate XXI B shows the loss in flow separated into underflow and evaporation-transpiration losses on the lower half of the graph. The sum of these two curves on the lower half of this graph represents the difference between the two curves shown in Plate XXI A. Daily averages were obtained from the evaporation-transpiration curve by the use of a planimeter. The upper half of the graph shows the daily rate of loss in inches of depth due to evaporation and transpiration.

A summary of results is given in Table 33, which shows the daily losses and weekly totals. For the 30-day period from April 28 to May 27, inclusive, the total loss was 12.9 acre-inches per acre. This was three times the loss from a free water lake surface as indicated by a Class A Weather Bureau type of pan located at Ontario. For the same 30-day period, the indicated loss from a lake surface was 4.3 inches.

Supporting Tank Data.

In support of the data obtained from the stream flow measurements, two tanks were installed in August, 1929. The tanks were set 30 feet upstream from the break in the old dam. Tank A was planted to tules and reeds, while willows only were set in Tank B. Measurements were started October 1, 1929, and carried through to June 4, 1930, at this location. The willow shoots in Tank B died back during the winter and swamp grass and weeds gradually possessed the tank until, by March, the willows were but a minor portion of the growth in Tank B. Plate XX A shows the growth in the tanks on June 4.

Tank B was moved to Ontario on June 4 and fitted with an automatic feed and recorded. Plate XX B shows Tank B at Ontario in July, 1930. The continuous record of the rate of use of water in Tank B is shown in Plate XXI C for the month of August, 1930. The rate of use curve was plotted from hourly readings from the automatic recorder charts.* Table 34 shows the monthly loss from the two tanks, and Table 35 the weekly losses from Tank A.

TABLE 33

SUMMARY OF RESULTS SHOWING INDICATED EVAPORATION-TRANSPIRATION LOSSES AT TEMESCAL CREEK

April 16 to May 27, 1929

Date	Average rate of loss in second-feet due to evaporation-transpiration	Loss per day in acre-inches	Rate of loss in acre-inches per acre per day	Rate of loss in acre-inches per acre per week	Date	Average rate of loss in second-feet due to evaporation-transpiration	Loss per day in acre-inches	Rate of loss in acre-inches per acre per day	Rate of loss in acre-inches per acre per week
April 16	0.010	0.238	0.02		May 7	0.150	3.570	0.28	
April 17	0.035	0.833	0.06		May 8	0.176	4.189	0.33	
April 18	0.026	0.619	0.05		May 9	0.178	4.237	0.33	
April 19	0.011	0.262	0.02		May 10	0.188	4.475	0.35	
April 20	0.024	0.571	0.04		May 11	0.220	5.236	0.41	
April 21	0.042	1.000	0.08		May 12	0.234	5.570	0.44	
April 22	0.043	1.023	0.08	0.35	May 13	0.259	6.165	0.48	2.62
April 23	0.052	1.238	0.10		May 14	0.290	6.902	0.54	
April 24	0.070	1.666	0.13		May 15	0.298	7.093	0.55	
April 25	0.078	1.857	0.14		May 16	0.298	7.093	0.55	
April 26	0.080	1.904	0.15		May 17	0.307	7.307	0.57	
April 27	0.079	1.880	0.15		May 18	0.278	6.617	0.52	
April 28	0.094	2.237	0.17		May 19	0.268	6.379	0.50	
April 29	0.105	2.499	0.20	1.04	May 20	0.267	6.355	0.50	3.73
April 30	0.118	2.809	0.22		May 21	0.297	7.069	0.55	
May 1	0.132	3.142	0.25		May 22	0.298	7.093	0.55	
May 2	0.162	3.856	0.30		May 23	0.318	7.569	0.59	
May 3	0.156	3.713	0.29		May 24	0.330	7.855	0.61	
May 4	0.163	3.880	0.30		May 25	0.353	8.402	0.66	
May 5	0.154	3.665	0.29		May 26	0.347	8.259	0.65	
May 6	0.152	3.618	0.28	1.93	May 27	0.343	8.164	0.64	4.25

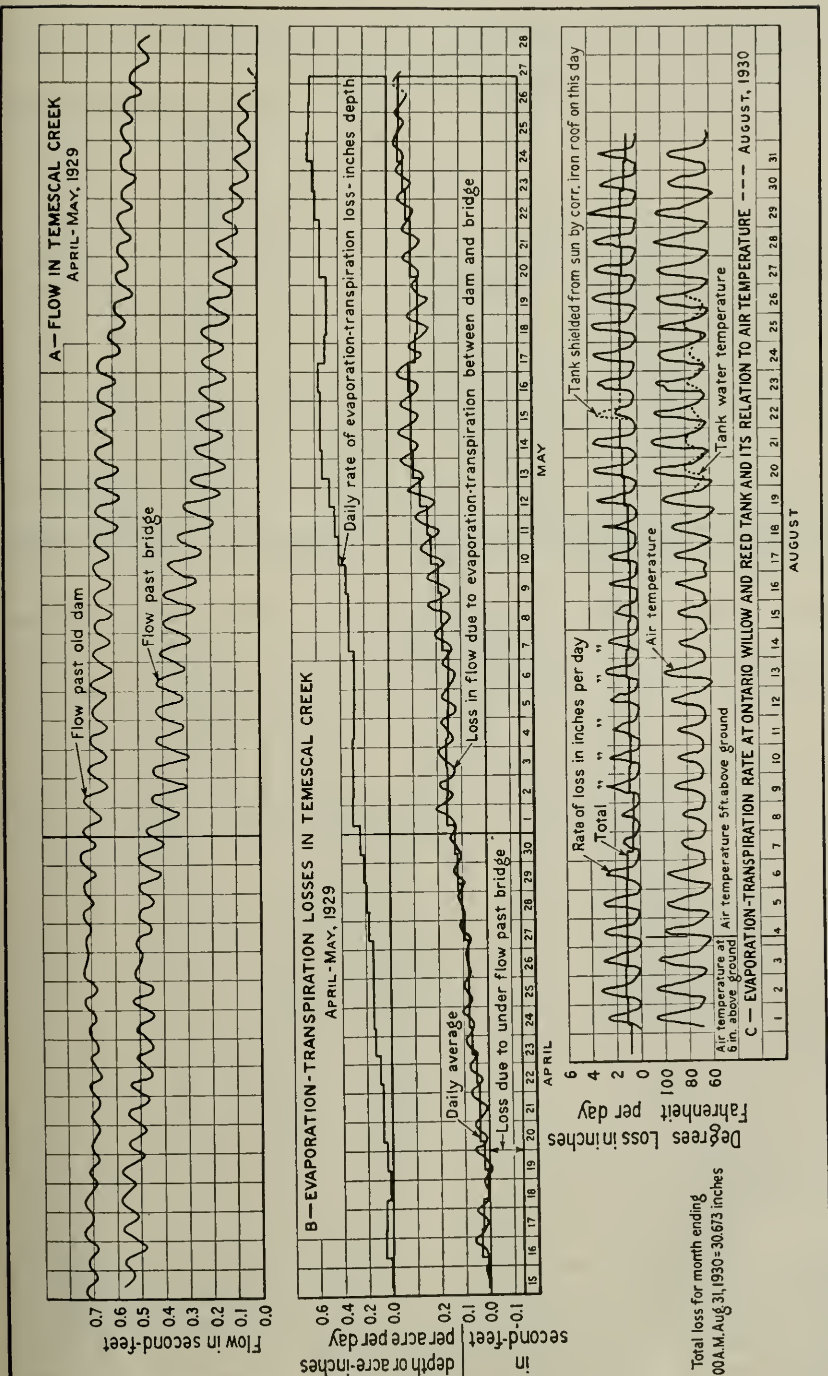
In Plate XXI C, the rate of use of water is shown to vary directly with the temperature of the air and to have the same time phase within rather close limits. The curves of stream flow in Plate XXI A have daily trends of maxima and minima similar to those of the transpiration-evaporation and temperature curves in Plate XXI C. However, the time of minimum stream flow occurs several hours later in the day than the time of maximum temperature and transpiration rate. This indicates a general lowering of the water plane over the moist area during the hours of maximum temperature. The time-lag of the hour of minimum stream flow behind the hour of maximum temperature depends on the speed with which the general draft on the water table is compensated for by water from the stream channel. During periods of hot weather, the draft on the water table may not be entirely replaced by water from the stream channel within a 24-hour period. In that case the trend of the mean daily discharge of the stream is downward.

* The automatic record from which the transpiration-evaporation curve in Plate XXI C was plotted was obtained by using a sensitive float valve feed from a supply tank to the willow and reed tank. The loss from the supply tank and the minute changes in water level in the willow and reed tank were recorded continuously on the same chart. The water level in the willow and reed tank was maintained three inches deep over the soil surface.

PLATE XX

TEMESCAL CREEK SWAMP TANKS.

A. Tank A (right) and Tank B (left), June, 1930.
B. Tank B at Ontario in July, 1930.



FLOW AND EVAPORATION-TRANSPIRATION LOSSES IN TEMESCAL CREEK, 1929, AND RATE OF EVAPORATION-TRANSPIRATION COMPARED TO AIR TEMPERATURES AT ONTARIO, 1930.

TABLE 34

MONTHLY LOSS OF WATER BY EVAPORATION AND TRANSPIRATION FROM TANKS A AND B AT TEMESCAL CREEK AND ONTARIO

October, 1929, to August, 1930

Date	Location	[1]Tule Tank A, loss per month in inches	[2]Willow and Reed Tank B, loss per month in inches
1929—			
October	Temescal Creek	16.79	6.64
November	Temescal Creek	9.15	5.52
December	Temescal Creek	4.83	3.81
1930—			
January	Temescal Creek	3.91	4.23
February	Temescal Creek	2.74	2.95
March	Temescal Creek	4.82	4.61
April	Temescal Creek	11.53	9.19
May	Temescal Creek	14.33	14.37
June	Ontario	------------	18.45
July	Ontario	------------	29.60
August	Ontario	------------	30.67

[1] Tules planted in Tank A, August 24, 1929.
[2] Tank B planted to willows August 26, 1929, but swamp grass and reeds gradually possessed the tank until by March, 1930, the willows were but a minor portion of the growth in the tank. Tank B was moved to Ontario on June 4, 1930.

TABLE 35

WEEKLY LOSS OF WATER BY EVAPORATION AND TRANSPIRATION FROM TEMESCAL TULE TANK A

October, 1929, to June, 1930[1]

Week ending	Loss per week in inches	Week ending	Loss per week in inches
1929—		1930—	
October 7	4.40	January 6	1.36
October 14	3.57	January 13	1.36
October 21	3.54	January 20	0.67
October 28	4.02	January 27	0.44
November 4	2.95	February 3	0.45
November 11	2.40	February 10	0.73
November 18	2.22	February 17	0.74
November 25	1.86	February 24	0.69
December 2	1.36	March 3	0.70
December 9	0.97	March 10	0.70
December 16	0.98	March 17	0.71
December 23	1.15	March 24	0.72
December 30	1.16	March 31	2.39
		April 7	1.76
		April 14	2.27
		April 21	3.17
		April 28	3.17
		May 5	2.96
		May 12	2.26
		May 19	2.63
		May 26	4.08
		June 2	4.56

[1] Tules planted in tank August 24, 1929.

It may then be stated that the moist land growth bordering a stream channel such as Temescal Creek has a marked influence on the flow of the stream. There is a daily fluctuation in flow to meet the transpiration demands of the bordering plant growth and a seasonal decrease in flow as the transpiration rate increases. The peak demand of transpiration on the water of the stream may be expected in July and August.

Air temperature is shown to be a direct indicator of the transpiration rate and hence of the stream flow. High temperatures cause extremely high rates of transpiration and correspondingly low stream flows.

This loss may be largely prevented by carrying the streams in lined canals or pipes and by lowering the water table by pumping in areas of rising water during the period from May 1 to October 1.

Probable Limits to the Losses Along Stream Channels.

The indicated loss of 12.9 inches in 30 days at Temescal Creek, together with still higher rates of loss from small isolated tanks of swamp growth, has led to a consideration as to what the probable limits for losses in moist areas along stream channels might be. The radiant energy received from the sun, or insolation as it is termed, suggests certain upper limits to the amount of water that may be vaporized over large swamp areas. Average daily records of insolation are published in the Monthly Weather Review for stations at La Jolla, Pasadena and Fresno. The equivalent water of vaporization for the insolation received at Pasadena and Fresno for the calendar year 1929 is as follows:

Station	Total annual insolation[1]	Equivalent water of vaporization at 68 degrees Fahrenheit
	Gram calories per square centimeter	Depth in feet
Pasadena	165,416	9.27
Fresno	169,691	9.51
Average		9.39

[1] Direct plus diffuse received on a horizontal surface.

This suggests that, if all of the radiant energy received from the sun were used in vaporizing water, it would be possible to lose 9.39 acre-feet per acre annually, as an average for the two stations, as the result of insolation.

Using the Fresno records for the period April 28 to May 27, 1929, we have the insolation as 20,467 gram calories per square centimeter and the equivalent water of vaporization at 68 degrees Fahrenheit as 13.8 inches. This is for the same period that the indicated loss from the swamp on Temescal Creek was 12.9 inches. It is likely, then, that the rate of loss was approaching its probable maximum when the tests on Temescal Creek ceased, due to a failing water supply late in May. There is some additional supply of heat to the swamp area from the surrounding rocky canyon walls and from the strong draft of air flowing through the canyon. On the other hand, not all of the insolation received directly on the swamp area is used in vaporization. Some of the radiant energy is stored in combination within the plant tissues, some is reflected from the plant surfaces and part goes into heat storage and in part is again radiated back to the sky.

The discussion of the receipt of energy, other than the vertical component from the sun, leads to a consideration of what the effect might be on very small patches of swamp growth. The extreme case may well be considered as an isolated tank of swamp growth two feet in diameter set in otherwise barren ground. The radiant energy intercepted by the plant growth in the tank must necessarily be a greater amount than the same area of growth in a swamp would receive because the isolated tank growth has a side exposure that in a swamp would be protected by surrounding plants. The analogy that might be drawn is that of a lens focusing the sun's rays on the restricted area of the tank.

Take the case of the two-foot tank used at Ontario in studying the correlation between air temperature and transpiration. The loss for the month of August, 1930, from the Ontario willow and reed tank was 30.67 inches depth. This is about two and one-half times the depth of water that could be vaporized by the insolation falling on the horizontal area of the tank. A partial explanation is that the tall growth in the isolated tank intercepts a much larger amount of insolation than the same area of growth would receive in a swamp. But in the case of the small tank, the heat energy brought to the growth in the tank by air movement also is relatively large. An experiment investigating this point was performed at Ontario on August 22, 1930. On this date, the willow and reed tank was shielded from the direct rays of the sun by a corrugated iron roof, eight by ten feet, placed just high enough to clear the plants and allow free lateral wind movement. The record of water loss is shown in Plate XXIC. The full line on August 22 is the actual loss with the tank shielded. The dotted line is the average of August 21 and 23. The values are:

Loss August 21	1.296 inches
Loss August 23	1.274 inches
Average loss for August 21 and 23	1.285 inches
Loss August 22	0.778 inches (with tank shielded)

The heat supply for vaporizing this 0.778 inches of water on August 22 must have come almost entirely from the moving air currents passing through the growth in the tank.

However, when a large swamp area is considered, there must be a rapid drop in temperature of the air as it passes through the swamp growth if it is to give up its heat supply at the rate indicated by the above experiment. As soon as the air is cooled to the same temperature as the plants there can be no further transfer of heat from the air to the plants. When this condition is reached, the energy for vaporization must come solely from insolation.

It may be expected, then, that small isolated patches of swamp growth will show rates of loss per unit area higher than that accounted for by insolation alone, but it also is probable that the loss from an extensive swamp area is limited to a value not widely variant from that indicated by insolation.

The inference is that in conducting tank work to gain data for use in estimating losses from field areas, that the tank should be set in a field of growth similar to that in the tank and the outside growth must completely surround the tank so the exposure of the growth in the tank is normal.

CHAPTER V

AREAS OF IRRIGATED LAND

Land in the Santa Ana River area cropped during the summer is generally irrigated, although some deciduous orchards and vineyards are exceptions to the general rule.

All citrus crops within the area require irrigation, but the amount of water applied varies widely, being dependent on the immediately available supply. In the basins having the least water, the amount applied on citrus land is quite often insufficient to moisten the entire root zone. As a result, there is an increasing soil moisture deficiency as the summer season progresses, and the groves in such basins enter the winter season with a relatively dry root zone capable of absorbing a large portion of the winter rainfall. On the other hand, in basins having a surplus of water, citrus crops may be heavily irrigated so that the root zone is then relatively moist when the rains come and a considerable portion of the rainfall percolates through the root zone and reaches the underground water table.

Deciduous orchards and vineyards are usually handled in such a manner as to retain much of the winter rainfall within the root zone. There is generally a large soil moisture deficiency in the fall of the year, and, where irrigation is practiced during the dormant season, it is usually delayed as long as practicable in the hope that there will be sufficient rain to thoroughly moisten the root zone.

The disposition of rainfall in cultivated areas is described in the following pages.

Citrus Orchards.

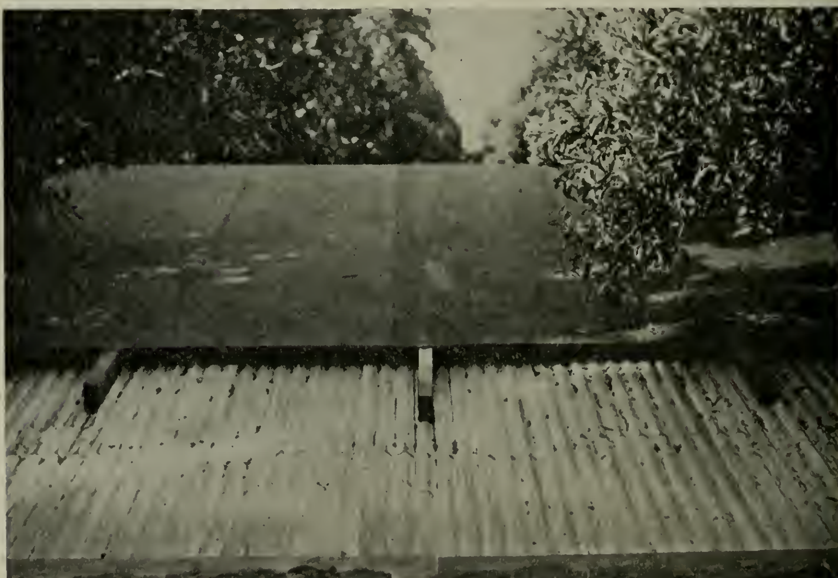
Ebert Plots.—The Ebert plots, A and B, are located in a mature Navel orange grove. The soil type is Hanford fine sandy loam to a depth of five feet and is fairly free from rock to that depth. The soil type was the major factor in the selection of this grove for study as over 2000 soil samples are required annually from each plot in order that accurate determinations regarding the disposal of rain and consumptive use of water can be made.

Each plot consists of a square of four trees, and seventeen definite points of sampling are located within the square. Sets of samples are taken at intervals of from ten days to two weeks.

For an absolute check on the winter transpiration by citrus, a cover plot was established in this grove after the rainfall was sufficient to fill the soil within the root zone to field capacity. By preventing rain from falling on the plots, except as desired, the amount of moisture in the soil was controlled, and thus more reliable data were obtained from soil sampling. An oiled canvas was placed on a framework beneath the tree branches at one four-tree square so that the soil was protected from rain within and to a distance of eight feet beyond each side of the square. Plate XXII is a photograph of this plot. Soil moisture records then were kept without interference from the frequent rains. A record of soil moisture extraction in one-foot sections down to a depth of six feet was kept for this plot throughout the year. The results showing use of water by transpiration are summarized in Tables 36 and 37. Plate XXIII is a graphical presentation of the results from Plot A for 1928-29. Tables 38 and 39 show the disposal of rain for 1928-29 and 1929-30 seasons.

Holden Plot.—The Holden grove of mature naval orange trees is located in the Arlington district west of Riverside. An excellent record of winter rate of tranpiration was obtained from Plot E in this grove

PLATE XXII



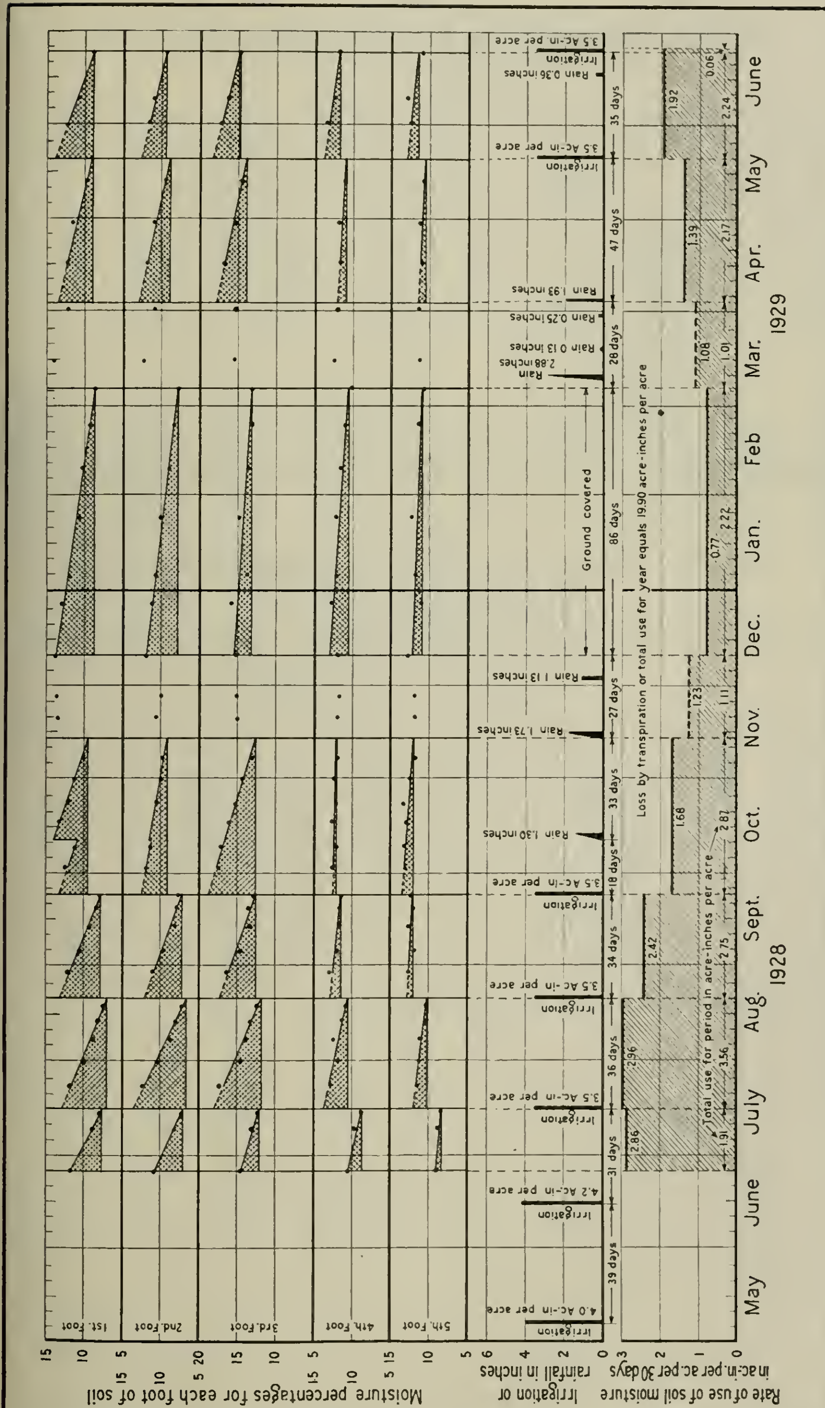
TRANSPIRATION FROM CITRUS TREES DURING RAINY SEASON. COVERED PLOT IN EBERT GROVE. FEBRUARY, 1929.

between November 25, 1929, and January 3, 1930. The rate for this 39-day period was found to be 1.41 acre-inches per acre per 30 days.

The greatest deficiency in soil moisture during the winter occurred just prior to the start of the January rains when the indicated deficiency was 3.09 acre-inches per acre below field capacity. This value includes the deficiency in the soil mulch.

The amount and distribution of the rain for 1929-30 were such that it all was held within the root zone until May 1. The grove was very heavily irrigated on April 26-30 so that when the early May rains started the soil was very wet. Due to the heavy rains added to the excessive irrigation, the soil below the second foot was still above field capacity on May 15, ten days after the end of the rain on May 5.

PLATE XXIII



TRANSPIRATION LOSSES FROM NAVEL ORANGE TREES, EBERT GROVE, 1928–1929.

TABLE 36

MONTHLY TRANSPIRATION USE OF WATER[1]—EBERT GROVE, PLOT A
MATURE NAVEL ORANGE TREES

July, 1928, to June, 1930

Month	Use of water in acre-inches per acre		
	1928	1929	1930
January	----------	0.80	----------
February	----------	0.72	1.02
March	----------	1.05	1.13
April	----------	1.36	1.09
May	----------	1.63	1.40
June	----------	1.92	1.40
July	3.01	----------	----------
August	2.86	----------	----------
September	2.25	----------	----------
October	1.74	----------	----------
November	1.43	----------	----------
December	0.95	----------	----------

[1] The "transpiration use of water" is the actual amount of water extracted from the soil by root action and is mainly transpiration. The loss by evaporation from the four-inch loose soil mulch is not included in these figures.

TABLE 37

MONTHLY TRANSPIRATION USE OF WATER—EBERT GROVE, PLOT B
MATURE NAVEL ORANGE TREES

March, 1929, to June, 1930

Month	Use of water in acre-inches per acre	
	1929	1930
January	----------	1.29
February	----------	1.16
March	1.74	1.50
April	1.72	1.95
May	2.22	2.09
June	2.81	[1]2.18
July	[1]3.28	----------
August	3.15	----------
September	1.91	----------
October	2.16	----------
November	1.53	----------
December	1.35	----------

[1] Total use July 1, 1929, to June 30, 1930, 23.55 acre-inches per acre.

TABLE 38

DISPOSAL OF RAINFALL—EBERT GROVE, PLOT B
MATURE NAVEL ORANGE TREES

Season of 1928–29

Date of soil sampling	Total rain to date in inches	Amount of rain since last date of sampling in inches	Soil moisture deficiency on date of sampling (below mulch) in inches	Gain or loss in soil moisture since last date of sampling (below mulch) in inches	Loss by transpiration since last date of sampling in inches	Amount of rain lost by evaporation or stored in mulch in inches	Local run-off in inches	Penetration below five-foot level in inches	Local run-off plus deep penetration in inches
1929—									
Jan. 5	6.19		2.07						
Jan. 27	8.01	1.82	1.34	0.73	0.73	0.34	0.02	0.00	0.02
Feb. 9	9.09	1.08	0.98	0.36	0.43	0.28	0.01	0.00	0.01
Mar. 6	9.86	0.77	1.88	—0.90	0.97	0.70	0.00	0.00	0.00
Mar. 16	12.74	2.88	[1]+0.14	2.02	0.56	0.20	0.10	0.00	0.10
April 1	13.12	0.38	0.89	—1.03	0.90	0.38	0.00	0.13	0.13
April 16	15.05	1.93	0.57	0.32	0.84	0.67	0.00	0.10	0.10
April 29	15.05	0.00	1.34	—0.77	0.77		0.00	0.00	0.00
May 13	15.05	0.00	2.16	—0.82	0.82		0.00	0.00	0.00

[1] Surcharge was in second and third feet.

TABLE 39

DISPOSAL OF RAINFALL—EBERT GROVE, PLOT B
MATURE NAVEL ORANGE TREES

Season of 1929–30

Date of soil sampling	Total rain to date in inches	Amount of rain since last date of sampling in inches	Soil moisture deficiency on date of sampling (below mulch) in inches	Gain or loss in soil moisture since last date of sampling (below mulch) in inches	Loss by transpiration since last date of sampling in inches	Amount of rain lost by evaporation or stored in mulch in inches	Local run-off in inches	Penetration below five-foot level in inches	Local run-off plus deep penetration in inches
1929—									
Oct. 3		0.55	2.41						
Oct. 7[1]									
Oct. 18			1.53	0.88	1.15				
Nov. 9[1]			3.26	—1.73	1.74				
Nov. 20			.91	2.35	.53				
Dec. 10			1.93	—1.02	.97				
Dec. 23			2.51	—.58	.63				
Dec. 28[2]			.00	2.51	.24				
1930—									
Jan. 25	6.50	5.95	0.14	—0.14	1.12	0.37	0.13	4.47	4.60
Feb. 21	7.22	.72	1.13	—.99	1.12	.59		.00	
Mar. 1	7.89	.67	1.20	—.07	.33	.41		.00	
April 3	12.73	4.84	.42	.78	1.62	1.14	.06	1.24	1.30
April 23			1.72	—1.30	1.30			.00	
May 22	15.56	2.83	1.58	.14	1.89	.80		.00	
June 13			3.17	—1.59	1.59			.00	
Totals	15.56								5.90

[1] Irrigated.
[2] Irrigated, 3.5 acre-inches per acre.

The excessive irrigation prevented an accurate determination of the disposal of the May rains, but the saturated soil condition on May 15 indicated a deep penetration below the root zone for both rain and irrigation water.

Woodbridge and Buchanan Plots.—After development of the compressed air unit for driving the soil tubes and the soil tube jack for pulling the tubes it was possible to do intensive work in the rocky soils of the Ontario-Upland district. Accordingly, in the fall of 1929, a plot was established on the Woodbridge grove in Upland and one on the Buchanan grove in Ontario. The disposal of rain for the season of 1929-30 on the Woodbridge plot is shown in Table 40 and for the Buchanan plot in Table 41.

TABLE 40

DISPOSAL OF RAINFALL—WOODBRIDGE PLOT[1]
MATURE LEMON TREES

Season of 1929-30

Date of soil sampling	Total rain to date in inches	Amount of rain since last date of sampling in inches	Soil moisture deficiency on date of sampling (below mulch) in inches	Gain or loss in soil moisture since last date of sampling (below mulch) in inches	Loss by transpiration since last date of sampling in inches	Amount of rain lost by evaporation or stored in mulch in inches	Penetration below six-foot level in inches
Unirrigated section along tree line (40 per cent of area)							
1929—							
December 13	0.51		4.86				
1930—							
January 18	7.83	7.32	+0.13	4.99	1.53	0.70	0.10
Irrigated section (60 per cent of area)							
1929—							
December 13	0.51		2.31				
December 21	0.51		2.66	—0.35	0.35	0.00	0.00
December 22 (irrigated)							
1930—							
January 3	0.51	0.00	0.14	+2.52	0.56	0.00	0.00
January 18	7.83	7.32	+0.95	+1.09	0.62	0.70	4.91
Whole plot							
February 19	8.35	0.52	1.12	—2.17	1.33	0.52	0.84
March 28	13.78	5.43	0.46	+0.66	1.73	1.00	2.04
April 23	13.95	0.17	1.89	—1.43	1.43	0.17	0.00
May 19	18.74	4.79	0.33	+1.56	1.73	0.80	0.70

[1]Note—No surface run-off.
Total penetration below six-foot level in unirrigated section along tree line, 3.68 inches.
Total penetration below six-foot level in irrigated section, 8.49 inches.
Average equivalent penetration below six-foot level over entire plot, 6.57 inches.

TABLE 41

DISPOSAL OF RAINFALL—BUCHANAN PLOT
MATURE NAVEL AND VALENCIA ORANGE TREES

Season of 1929-30

Date of soil sampling	Total rain to date in inches	Amount of rain since last date of sampling in inches	Soil moisture deficiency on date of sampling (below mulch) in inches	Gain or loss in soil moisture since last date of sampling (below mulch) in inches	Loss by transpiration since last date of sampling in inches	Amount of rain lost by evaporation or stored in mulch in inches	Penetration below six-foot level in inches
Unirrigated section along tree line (40 per cent of area)							
1929—							
December 10	0.62	----------	2.84	----------	----------	----------	----------
December 27	0.62	----------	3.42	−0.58	0.58	0.00	0.00
1930—							
January 18	5.98	5.36	+0.81	+4.23	0.43	0.70	0.00
Irrigated section (60 per cent of area)							
1929—							
December 10	0.62	----------	0.26	----------	----------	----------	----------
December 27	0.62	----------	1.58	−1.32	1.32	0.00	0.00
1930—							
January 18	5.98	5.36	+1.99	+3.57	0.74	0.70	0.35
Whole plot							
February 19	6.65	0.67	1.09	−3.08	1.07	0.60	2.08
March 28	13.37	6.72	+0.02	+1.11	1.37	1.00	3.24
April 23	13.54	0.17	1.97	−1.99	1.99	0.17	0.00
May 20	16.76	3.22	1.16	+0.81	1.42	0.80	0.19

[1]Note—No surface run-off.
Total penetration below six-foot level in section along tree line, 3.43 inches.
Total penetration below six-foot level in regularly irrigated section, 5.86 inches.
Average equivalent penetration below six-foot level on entire grove, 4.89 inches.

Comparison of Penetration of Rainfall in Citrus Plots.—Summarizing the results for 1929-30 for the three citrus plots on which quantitative data were obtained for the deep penetration below the root zone, we have:

Plot	Season	Rainfall in inches	Penetration below root zone in inches
Ebert	1929–30	15.56	5.90
Woodbridge	1929–30	18.74	6.57
Buchanan	1929–30	16.76	4.89

Both the Ebert grove and the Woodbridge grove were irrigated late in December, so there was very little deficiency in soil moisture when the January rains started. The Buchanan plot had a deficiency of 1.9 acre-inches per acre in the irrigated section at that period and this plot shows the lowest value for deep penetration below the root zone.

A thorough inspection of the soil moisture conditions in citrus groves of the Santa Ana River area in May, 1930, showed all of the root zone thoroughly moistened. This is evidence of a general contribution of rainfall to the ground water supply by direct penetration of moisture through the root zone.

Deciduous Orchards.

Walline Plot.—The Walline peach plot is located in an orchard four miles east of Ontario. The soil is a uniform Hanford sand to a depth of fifteen feet, and below this depth it is somewhat silty with occasional gravel pockets.

The peach variety is Tuscan Cling and the trees were set out in 1916. Irrigation in this grove is accomplished with the furrow and cross-check system. The standard orchard plot method of soil sampling was used with seventeen points of sampling within the square of four trees. Table 42 shows disposal of rain and Table 43 the use of water throughout the year.

TABLE 42

DEFICIENCY OF SOIL MOISTURE AND DISPOSAL OF RAINFALL—WALLINE PLOT TUSCAN CLING PEACHES

Season of 1928-29

Date of soil sampling	Amount of rain since last date of sampling in inches	Gain in soil moisture since last date of sampling (below mulch) in inches	Amount of rain lost by evaporation or stored in mulch in inches	Total rain to date in inches	Total amount of rain stored in soil (below mulch) in inches	Total amount of rain lost by evaporation in inches	Soil moisture deficiency (below mulch) in inches
1928—							
Initial fall deficiency							13.85
November 21	1.54	0.56	0.98	1.54	0.56	0.98	13.29
December 28	2.38	1.49	0.89	3.92	2.05	1.87	11.80
1929—							
January 23	1.93	1.43	0.50	5.85	3.48	2.37	10.37
February 28	1.38	1.23	0.15	7.23	4.71	2.52	9.14
April 8	3.79	2.55	1.24	11.02	7.26	3.76	6.59

TABLE 43

USE OF WATER—WALLINE PLOT, TUSCAN CLING PEACHES, ONTARIO, 1928

1928	Transpiration use in acre-inches per acre[1]	1928	Transpiration use in acre-inches per acre[1]
January	0.0	July	8.0
February	0.0	August	6.0
March	0.0	September	2.7
April	0.5	October	0.9
May	3.0	November	0.2
June	6.2	December	0.0

Transpiration, total for year	27.5 inches
Evaporation, winter rains	4.3 inches
Evaporation, irrigation	2.0 inches
Total annual evaporation-transpiration	33.8 inches

[1] From upper fifteen feet of soil.

Rainfall Penetration Tests by Inspection.—General soil moisture surveys were made by crops at the end of the rainy reason in 1929 and again in 1930. Usually the depth of rain penetration could be determined from an examination of the soil tube cores as the soil would be distinctly dry below the depth of the seasonal moisture penetration. If no dry soil was found, borings were made to depths of twelve, fifteen or eighteen feet, depending on the crop, and the notation "no dry soil" recorded.

Deciduous orchards irrigated in the late fall or winter were generally moist to the full depth of the root zone.

Nonirrigated orchards in poor condition due to lack of care or poor soil were found to be relatively shallow rooted, while the more vigorous orchards and vineyards showed root activity to fifteen and eighteen-foot depths. This was indicated by dry soil at such depths. The records for the 1928–29 and 1929–30 seasons are given in Tables 44 to 49, inclusive.

TABLE 44

PENETRATION OF RAINFALL IN PEACH AND APRICOT ORCHARDS AS DETERMINED BY FIELD INSPECTION

Season of 1928-29

Hole No.	Date of sampling	Total rain to date in inches	Depth of penetration in feet
Tests in unirrigated areas			
2	April 24, 1929	11.07	9.5
3	April 24, 1929	11.07	5.3
4	April 24, 1929	11.07	9.0
5	April 25, 1929	11.07	7.5
6	April 25, 1929	11.07	No dry soil
7	April 25, 1929	11.07	10.0
8	April 25, 1929	11.07	9.3
9	April 26, 1929	11.07	8.3
10	April 26, 1929	11.07	No dry soil
11	April 26, 1929	11.07	7.2
12	April 26, 1929	11.07	No dry soil
16	April 26, 1929	13.13	8.5
18	April 26, 1929	13.13	7.2
Tests in irrigated areas			
1	April 24, 1929	11.07	No dry soil
13	April 26, 1929	13.13	No dry soil
14	April 26, 1929	13.13	No dry soil
15	April 26, 1929	13.13	No dry soil
17	April 26, 1929	13.13	8.5

TABLE 45

PENETRATION OF RAINFALL IN VINEYARDS AS DETERMINED BY FIELD INSPECTION

Season of 1928-29

Hole No.	Date of sampling	Total rain to date in inches	Depth of penetration in feet
Tests in unirrigated areas			
2	May 4, 1929	11.39	7.2
4	May 4, 1929	11.39	6.8
Tests in irrigated areas			
1	April 26, 1929	11.07	No dry soil
3	May 4, 1929	11.39	6.2
5	May 4, 1929	11.39	No dry soil

TABLE 46

PENETRATION OF RAINFALL IN WALNUT GROVES AS DETERMINED BY FIELD INSPECTION

Season of 1928-29

Hole No.	Date of sampling	Total rain to date in inches	Depth of penetration in feet
Tests in unirrigated areas			
13	May 2, 1929	13.13	4.5
14	May 2, 1929	13.13	5.5
18	May 2, 1929	13.13	5.5
Tests in irrigated areas			
1	April 27, 1929	13.13	4.5
2	April 27, 1929	13.13	5.0
3	April 27, 1929	13.13	5.5
4	April 27, 1929	13.13	9.0
5	May 2, 1929	13.13	11.0
6	May 2, 1929	13.13	No dry soil
7	May 2, 1929	13.13	12.0
8	May 2, 1929	13.13	14.0
9	May 2, 1929	13.13	12.0
10	May 2, 1929	13.13	No dry soil
11	May 2, 1929	13.13	14.0
12	May 2, 1929	13.13	No dry soil
15	May 2, 1929	13.13	No dry soil
16	May 2, 1929	13.13	No dry soil
17	May 2, 1929	13.13	No dry soil

TABLE 47

PENETRATION OF RAINFALL IN PEACH AND APRICOT ORCHARDS AS DETERMINED BY FIELD INSPECTION

Season of 1929-30

Hole No.	Date of sampling	Total rain to date in inches	Depth of penetration in feet
Tests in unirrigated areas			
19	April 14, 1930	9.16	4.0
20	April 14, 1930	9.16	4.0
21	April 14, 1930	9.16	3.5
22	April 14, 1930	9.16	3.3
23	April 14, 1930	9.16	4.0
24	April 14, 1930	9.16	7.5
25	April 14, 1930	9.16	6.0
27	April 14, 1930	11.95	No dry soil
29	April 15, 1930	13.54	8.5
30	April 15, 1930	13.54	10.0
33	April 15, 1930	12.32	7.0
34	April 15, 1930	12.32	9.0
35	April 15, 1930	12.32	6.0
37	April 15, 1930	12.32	6.0
41	April 15, 1930	12.32	5.4
Tests in irrigated areas			
26	April 14, 1930	11.95	No dry soil
28	April 14, 1930	13.54	No dry soil
31	April 15, 1930	13.54	No dry soil
32	April 15, 1930	12.32	No dry soil
36	April 15, 1930	12.32	No dry soil
38	April 15, 1930	12.32	No dry soil
39	April 15, 1930	12.32	No dry soil
40	April 15, 1930	12.32	No dry soil
42	April 15, 1930	12.32	No dry soil
43	April 15, 1930	12.32	No dry soil
44	April 15, 1930	12.32	No dry soil
45	April 15, 1930	13.54	No dry soil
46	April 15, 1930	13.54	11.5

TABLE 48

PENETRATION OF RAINFALL IN VINEYARDS AS DETERMINED BY FIELD INSPECTION

Season of 1929-30

Hole No.	Date of sampling	Total rain to date in inches	Depth of penetration in feet	Date of sampling	Total rain to date in inches	Depth of penetration in feet
Tests in unirrigated areas						
6	April 17, 1930	12.32	7.0	May 9, 1930	15.70	8.2
7	April 17, 1930	12.32	8.0	May 9, 1930	15.70	8.0
8	April 17, 1930	12.32	6.2	May 9, 1930	15.70	8.2
9	April 17, 1930	12.32	No dry soil	----------	----------	----------
10	April 17, 1930	12.32	5.0	May 9, 1930	15.70	9.0
11	April 17, 1930	12.32	8.0	May 9, 1930	15.70	9.3
12	April 17, 1930	12.32	8.0	May 9, 1930	15.70	9.0
Tests in irrigated areas						
13	April 17, 1930	12.32	No dry soil	----------	----------	----------

TABLE 49

PENETRATION OF RAINFALL IN WALNUT GROVES AS DETERMINED BY FIELD INSPECTION

Season of 1929-30

Hole No.	Date of sampling	Total rain to date in inches	Depth of penetration in feet
Tests in unirrigated areas			
22	May 16, 1930	14.73	6.5
Tests in irrigated areas			
19	May 16, 1930	14.73	5.0
20	May 16, 1930	14.73	No dry soil
21	May 16, 1930	14.73	No dry soil
23	May 16, 1930	14.73	No dry soil
24	May 16, 1930	14.73	No dry soil

Alfalfa.

Thomas Plot.—The alfalfa plot is located on the Thomas ranch, three miles southeast of Chino. The soil is a Hanford sand to a depth of four feet, shading into a silt loam at seven feet, and is quite sandy again in the thirteenth foot. Irrigation is accomplished by flooding with the aid of portable slip-joint pipe.

The plot is 48 feet square and six points of sampling are located eight feet apart across the center of the plot. Intensive sampling without disturbing the crop is accomplished by working from portable wooden horses.

None of the 1930 summer irrigation water penetrated to the twelve-foot level on the plot, and it is probable there was a considerable deficiency in soil moisture at the beginning of the rainy season. This, of course, will depend on the amount and time of fall irrigations. The rate of use of water from May to August, 1930, is shown in Table 50.

TABLE 50

CONSUMPTIVE USE OF WATER—ALFALFA PLOT, THOMAS RANCH, CHINO, 1930

Dates of irrigation	Dates crop was cut	Period studied	Rate of use in acre-inches per acre per 30 days
	May 12	May 12–May 23	4.03
May 26		June 7–July 1	5.50
July 12	July 18	July 21–Aug. 4	[1]3.54
Aug. 6	Aug. 21		
Sept. 12			

[1] Crop was cut July 18.

CHAPTER VI

FACTORS IN RAINFALL DISPOSAL

Initial Soil Moisture Deficiency.

As previously suggested there is at the beginning of almost every rainy season an initial deficiency of soil moisture within the root zone in the district being studied. During the summer months the capillary moisture is more or less completely withdrawn from the soil within the root zone by the processes of evaporation and transpiration. In non-irrigated soil the moisture content may be depleted until little more than hygroscopic water is left, while in irrigated soil, because of the artificial application of water, the moisture content may be much greater. Thus the deficiency of soil moisture below field capacity at the beginning of the rainy season is an important factor in limiting the amount of rainfall penetrating to ground water. Aside from the penetration due to local surface run-off, there can be no material penetration below the root zone until all of the soil within that zone has been supplied with its field capacity. The moisture content of the soil at the beginning of the rainy season varies with the last crop raised, type of soil, amount of irrigation water applied, evaporation, transpiration by plant life, depth of water table and other conditions. Citrus trees are shallow-rooted and their effect upon initial deficiency of soil moisture is small, while grape vines, deciduous trees and native brush are deep-rooted and draw from the soil moisture to greater depths, thus causing greater moisture deficiencies.

The initial fall deficieny in moisture content of the soil is determined as follows:

Soil samples are taken previous to the beginning of the rainy season and again later when the soil is at its field capacity, either as the result of rainfall or irrigation. The moisture content of these soil samples is determined by standard methods. The difference between the moisture content of the soil at field capacity and initial moisture content in the fall of the year is equal to the initial fall deficiency of soil moisture.

Summary of Plots.—The deficiency of soil moisture below field capacity at the beginning of the rainy season for the various experimental plots heretofore described is summarized in Table 51. The initial fall moisture deficiency for any particular plot may be considered a fairly definite amount for unirrigated lands, but for irrigated areas, especially citrus, the amount is variable, depending upon the irrigation practice.

Citrus and Walnut Plots, Orange County.—During the years 1927 and 1929, S. H. Beckett, Division of Irrigation Investigations and Practice, University of California, conducted a cooperative investigation in Orange County on the use of water by citrus and walnut trees. From the result of these studies, the following tables have been compiled:

TABLE 51

SUMMARY OF INITIAL FALL MOISTURE DEFICIENCY FOR VARIOUS PLOTS

Location	Crop	Soil type	Initial fall moisture deficiency of soil below field capacity in inches
Devil Canyon shaft	Brush	Hanford gravelly sandy loam	12.5
Muscoy Plot I	Brush	Hanford gravelly sand	9.0
Muscoy Plot J	Brush	Hanford gravelly sand	8.1
Palmer Canyon Plot K	Brush	Placentia clay loam	10.1
Plot B2	Brush	Hanford stony sandy loam	11.1
Plot B3	Brush	Hanford gravelly sandy loam	10.0
Plot B4	Brush	Tujunga stony sand	11.9
Plot B5	Brush	Tujunga stony sand	8.0
Plot B6	Brush	Hanford stony sandy loam	14.0
Plot B7	Brush	Hanford gravelly sandy loam	11.3
Plot B8	Brush	Hanford stony sandy loam	11.1
Devil Canyon Plot B	Weeds and grass	Hanford gravelly sandy loam	6.9
Plot A1	Weeds and grass	Hanford fine sandy loam	5.8
Plot A2	Weeds and grass	Hanford fine sandy loam	4.6
Plot D1	Weeds and sunflowers	Hanford sand	13.2
Plot E1	Grass and weeds	Hanford sand	7.6
Plot E2	Grass and weeds	Hanford sand	6.0
Plot F	Grass and weeds	Hanford loam	7.1
Plot H2	Barley	Placentia loam	4.3
Ebert Plot A	Citrus	Hanford fine sandy loam	
(September 23, 1928)			3.0
(October 9, 1928)			[2]0.8
Ebert Plot B	Citrus	Hanford fine sandy loam	
(October 3, 1929)			2.9
(December 28, 1929)[1]			[2]0.0
Holden Plot	Citrus	Hanford loam	3.1
Woodbridge Plot	Citrus	Hanford gravelly sandy loam	
(December 13, 1929)[1]			2.5
(January 3, 1930)[1]			[2]0.6
Buchanan Plot	Citrus	Hanford gravelly sandy loam	
(December 27, 1930)[1]			2.1
Plot H1	Citrus	Placentia loam	3.4
Walline Plot	Peaches	Hanford sand	14.3
Plot G1	Peaches	Placentia loam	8.2
Plot G2	Peaches	Placentia loam	8.5

[1] Prior to major rains.
[2] Grove had been recently irrigated.

TABLE 52

DEFICIENCY OF SOIL MOISTURE IN CITRUS GROVES, ORANGE COUNTY, 1928

Depth of sample in feet	Deficiency of soil moisture						
	Station 17A	Station 17B	Station 19A	Station 19B	Station 20A	Station 21A	Station 21B
	October 10	October 10	November 8	October 22	October 22	October 26	October 25
	In inches[1]	In inches[1]	In inches[1]	In inches[1]	In inches[1]	In inches[1]	In inches[1]
0-1	0.99	1.21	1.14	0.84	0.86	0.21	0.02
1-2	1.29	1.92	2.33	1.69	2.06	0.60	0.54
2-3	1.33	2.38	3.01	1.82	2.43	1.01	1.00
3-4	1.31	2.60	3.45	1.91	2.72	1.50	1.49
4-5	1.21	2.43	3.68	2.02	2.83	1.06	1.63
5-6	1.09	1.94	3.92	2.02	2.76	2.09	1.72

[1] Total to bottom of section.

Tables 52 and 53 show the deficiency of soil moisture for citrus plots on various dates in the fall, and Tables 54 and 55 show the maximum deficiency of soil moisture permissible under good irrigation practice on

TABLE 53

DEFICIENCY OF SOIL MOISTURE IN CITRUS GROVES, ORANGE COUNTY, 1929

Depth of sample in feet	Deficiency of soil moisture										
	Station 17C	Station 17C	Station 17D	Station 17D	Station 19C	Station 19C	Station 19D	Station 19D	Station 20B	Station 21A	Station 21A
	November 5	December 19	November 5	December 19	November 19	December 18	November 19	December 18	December 9	September 25	October 26
	In inches[1]	In inches[1]	In inches[1]	In inches[1]	In inches[1]	In inches[1]	In inches[1]	In inches[1]	In inches[1]	In inches[1]	In inches[1]
0–1	1.18	0.69	1.14	1.08	1.03	0.28	1.24	0.64	1.05	0.85	0.35
1–2	1.99	1.25	1.73	1.61	1.83	0.46	2.29	0.98	2.12	1.61	1.03
2–3	2.30	1.40	2.09	1.88	2.33	0.41	3.34	1.33	2.84	2.09	1.68
3–4	2.39	1.57	2.30	2.08	2.67	0.62	3.88	1.47	3.60	2.54	2.24
4–5	2.57	1.65	2.35	2.16	2.73	0.67	4.17	1.50	3.80	2.84	2.65
5–6	2.67	1.68	2.51	2.36	2.82	0.79	4.50	1.42	4.23	2.90	2.73

[1] Total to bottom of section.

the basis of root distribution. Tables 56 and 57 give similar information for walnuts. These values for soil moisture deficiency are for the root zone below the loose soil mulch.

TABLE 54

MAXIMUM DEFICIENCY OF SOIL MOISTURE UNDER GOOD IRRIGATION PRACTICE ON BASIS OF ROOT DISTRIBUTION FOR CITRUS, ORANGE COUNTY, 1928

Depth of sample in feet	Deficiency of soil moisture						
	Station 19A	Station 19B	Station 20A	Station 17A	Station 17B	Station 21A	Station 21B
	In inches	In inches	In inches	In inches	In inches	In inches	In inches
0-1	1.58	1.61	1.69	1.39	1.55	1.37	1.09
1-2	1.34	1.32	1.72	.46	1.35	.75	.55
2-3	.52	.27	.64	.23	.60	----------	----------
3-4	.48	.31	.54	.13	.36	.23	.22
4-5	.33	.22	.10	.02	.07	----------	----------
5-6	.25	.07	.06	.02	----------	.15	.24
Totals	4.50	3.80	4.75	2.25	3.93	2.50	2.10

TABLE 55

MAXIMUM DEFICIENCY OF SOIL MOISTURE UNDER GOOD IRRIGATION PRACTICE ON BASIS OF ROOT DISTRIBUTION FOR CITRUS, ORANGE COUNTY, 1929

Depth of sample in feet	Deficiency of soil moisture					
	Station 19C	Station 19D	Station 20B	Station 17C	Station 17D	Stations 21 A and B
	In inches	In inches	In inches	In inches	In inches	In inches
0-1	1.46	1.51	1.73	1.50	1.53	1.20
1-2	1.27	1.32	1.59	.42	.46	.94
2-3	.49	.51	.46	.10	.18	.45
3-4	.42	.44	.42	.06	.05	.44
4-5	.16	.20	.08	----------	.02	.20
5-6	.10	.12	.15	.01	.02	.07
Totals	3.90	4.10	4.43	2.09	2.26	3.30

TABLE 56

DEFICIENCY OF SOIL MOISTURE IN WALNUT GROVES, ORANGE COUNTY

Depth of sample in feet	Deficiency of soil moisture			
	Station 18A	Station 18B	Station 18C	Station 18D
	November 10, 1928	November 10, 1928	November 6, 1929	November 6, 1929
	In inches[1]	In inches[1]	In inches[1]	In inches[1]
0-3	5.34	5.34	5.04	4.20
3-6	10.26	10.86	8.64	6.54
6-9	12.90	15.06	10.89	9.39
9-12	----------	----------	13.05	11.01

[1] Total to bottom of section.

TABLE 57

MAXIMUM DEFICIENCY OF SOIL MOISTURE UNDER GOOD IRRIGATION PRACTICE ON BASIS OF ROOT DISTRIBUTION FOR WALNUTS, ORANGE COUNTY, 1928 AND 1929

Depth of sample in feet	Deficiency of soil moisture			
	Station 18A	Station 18B	Station 18C	Station 18D[*]
	In inches	In inches	In inches	In inches
0–3	5.10	5.12	4.90	4.42
3–6	4.33	2.64	4.45	4.00
6–9	1.51	1.86	1.48	0.80
9–12			0.35	0.64
Totals	10.94	9.62	11.18	9.86

Run-off.

Measurements of run-off from the mountain catchment areas into the valley and the surface water discharge from the basins have been made for some years by the United States Geological Survey and more intensive studies have been made during the last three years. Very little is known, however, as to the amounts of surface run-off from the valley floors, and plots have, therefore, been selected in typical soil and under other conditions with the view of making careful studies of such amounts.

A part of the surface run-off from the valley floors may be termed local as it flows directly into depressions and then percolates into the ground without reaching the main surface streams. This local surface run-off is measured volumetrically by collecting the discharges from small areas in suitable reservoirs. Measurements of the surface run-off from larger areas are made by installing Parshall measuring flumes* with automatic recorders in the drainage channels.

During the winters of 1927–28 and 1928–29 there was no measurable rainfall run-off from undisturbed soil with native cover. Certain cropped areas, however, showed noticeable amounts of run-off. This run-off occurred in areas cultivated several times during the year, particularly citrus groves. The greatest amount of run-off occurred on the ancient alluvial soils where a plow sole is most readily formed, but there also was some run-off in the groves on recent alluvial fine sandy loam. The gravelly areas around Upland and Claremont did not show any measurable run-off, but water stood in furrows in some groves in these areas and a slight increase in rainfall intensity would have caused run-off.

Records were obtained of the amount of run-off from rainfall at four locations during 1928–29, but its ratio to the total seasonal rain was less than three per cent, even on the intensely cultivated groves. All plots on soil with undisturbed cover showed no run-off during either the season of 1927–28 or 1928–29. The average contribution to ground water from local surface run-off of rainfall during the seasons of 1927–28 and 1928–29 therefore was considered to be of very minor importance.

* The improved Venturi flume, by R. L. Parshall; Bulletin 335, Colorado Agricultural College.

The records for the 1929–30 season indicate an appreciable contribution to the ground water by local surface run-off to low spots in the Riverside district of ancient alluvial soils. The season was one of above normal rainfall for the district and whenever the storms were of long duration or of high intensity appreciable run-off occurred.

One field of 11.8 acres that had an oat crop growing during the winter showed a total run-off of 3.55 inches, 28 per cent of the rainfall. For the same period, the run-off from an adjacent native brush plot was 0.74 inch, six per cent of the rainfall. Similar comparison by artificial rain tests shows an even more pronounced run-off from cultivated areas.

The penetration of rain by local surface run-off to low lying areas appears to be the principal avenue by which it reached the ground water in the Riverside area of ancient compact alluvial soils. Tables 58 to 61, inclusive, show the run-off records for the Riverside area for 1929–30 and Table 62 gives the intensity of rainfall at Riverside for the 1929–30 season.

TABLE 58

RAINFALL RUN-OFF FROM RIVERSIDE FIELD PLOT 1

5.28 Acres of Navel Oranges on Ramona Loam Soil

Date of storm causing run-off	Total rain for storm in inches	Total run-off for storm in inches
1930—		
January 9–12	3.36	0.71
January 14–16	.76	.05
January 26–27[1]	.52	.03
Totals	4.64	0.79

[1] No further record, as grove was disked, thereby destroying the drainage ditch.

TABLE 59

RAINFALL RUN-OFF FROM RIVERSIDE FIELD PLOT 6[1]

11.8 Acres of Oats on Ramona Loam Soil

Date of storm causing run-off	Total rain for storm in inches	Total run-off for storm in inches
1930—		
January 9–12	3.36	1.02
January 14–16	.76	Trace
January 26–27	.52	.11
March 4–5	.66	.18
March 14–17	2.61	1.29
March 31–April 1	.74	.32
April 30–May 2	1.83	.17
May 3–5	1.29	.46
Totals	11.77	3.55

[1]Note—Total rain January 5 to May 5, 1930 .... 12.69 inches
Total run-off January 5 to May 5, 1930 .... 3.55 inches
Per cent of run-off January 5 to May 5, 1930 .... 28 per cent

TABLE 60

RAINFALL RUN-OFF FROM RIVERSIDE PLOT 7—NATIVE BRUSH[1]

100 Square Feet in Plot on Ramona Loam Soil

Date of storm causing run-off	Total rain for storm in inches	Total run-off for storm in inches
1930—		
January 9–12	3.36	0.56
March 14–17	2.61	.18
Totals	5.97	0.74

[1]Note—Total rain January 5 to May 5, 1930 12.69 inches
Total run-off January 5 to May 5, 1930 0.74 inches
Per cent of run-off January 5 to May 5, 1930 6 per cent

TABLE 61

RAINFALL RUN-OFF FROM RIVERSIDE PLOT 8—CLEAN FURROW PLOT IN WALNUT GROVE

100 Square Feet in Plot on Ramona Loam Soil

Storm of March 30, March 31, April 1, 1930

Rain during two periods of high intensity	0.38 inch
Total run-off	.32 inch
Amount absorbed in nineteen minutes	0.06 inch
Absorption coefficient	0.19 inch per hour

TABLE 62

INTENSITY OF RAINFALL ON RIVERSIDE RUN-OFF PLOTS[1]

Table gives intensities of 0.20 inch per hour or higher

Date of storm	Start of interval	End of interval	Minutes in interval	Rainfall in inches during interval	Intensity of rainfall in inches per hour
1930—					
January 6	11:34 p.m.	11:39 p.m.	05	0.10	1.20
January 9	4:55 p.m.	6:00 p.m.	65	.24	.22
January 9	7:00 p.m.	9:00 p.m.	120	.50	.25
January 9	10:05 p.m.	10:38 p.m.	33	.17	.31
January 11	4:55 a.m.	7:25 a.m.	150	.83	.33
January 12	4:40 p.m.	5:28 p.m.	48	.22	.28
January 27	11:28 a.m.	11:40 a.m.	12	.04	.20
March 4	11:05 p.m.	11:18 p.m.	13	.13	.60
March 14	6:50 p.m.	8:50 p.m.	120	.63	.32
March 14	8:50 p.m.	11:20 p.m.	150	.59	.24
March 30	2:48 a.m.	2:58 a.m.	10	.11	.66
March 31	1:33 p.m.	1:52 p.m.	19	.27	.85
April 30	1:18 p.m.	1:35 p.m.	17	.12	.42
April 30	5:02 p.m.	5:32 p.m.	30	.10	.20
May 3	6:45 p.m.	6:55 p.m.	10	.13	.78
May 3	6:55 p.m.	7:20 p.m.	25	.14	.34
May 4	4:25 p.m.	4:40 p.m.	15	.10	.40

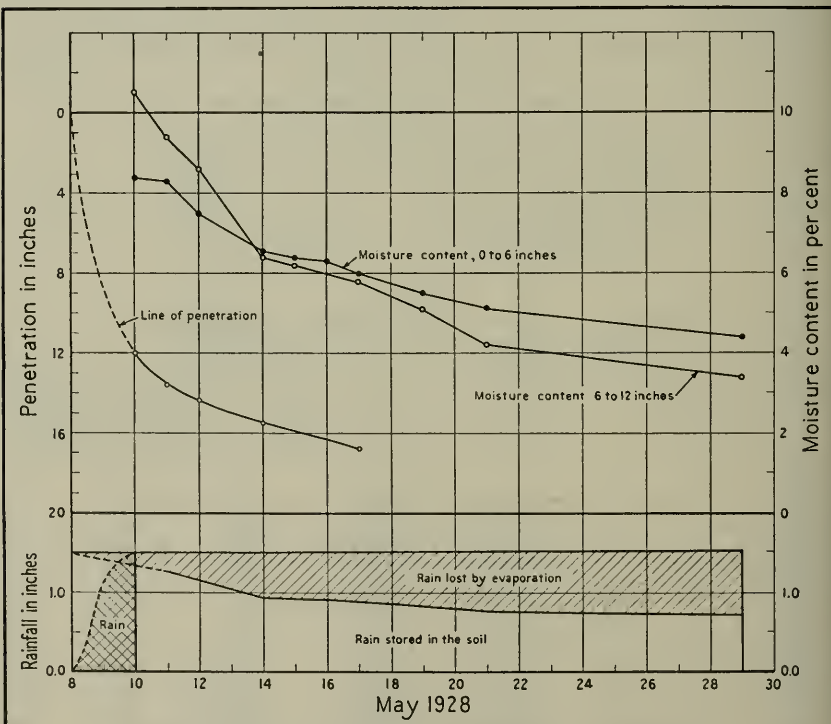
[1]Total rainfall January 5 to May 5, 1930=12.69 inches.

Evaporation and Transpiration Losses.

Evaporation From Bare Soil After Rain—Ontario Plot.—During the 1927–28 season, a late spring rain afforded an opportunity to observe the rate of evaporation from the soil surface following a rain. The plot used for the test had a winter crop of grass that had matured and died before the May rain so the soil was dry before the rain and the outline of penetration of the May rain could, therefore, be readily observed. The dead grass cover was removed so that the soil surface was bare.

The average depth of penetration was obtained by digging a trench twelve feet long and measuring the outline of the wetted soil. Soil samples were taken at six points along the face of the trench in six-inch increments of depth. On each succeeding date of sampling, the face of the trench was advanced six inches into undisturbed soil. The amount of rain stored in the soil was computed from the soil moisture data and the outline of penetration. Results are graphically shown in Plate XXIV. The total rain May 8 and 9 was 1.49 inches and 0.79 inch of this had evaporated by May 29. This may be considered as representative of late spring or early fall conditions. During the colder months of January and February, the evaporation is much less, as shown by the complete season's results for 1928–29 in Plate XXV.

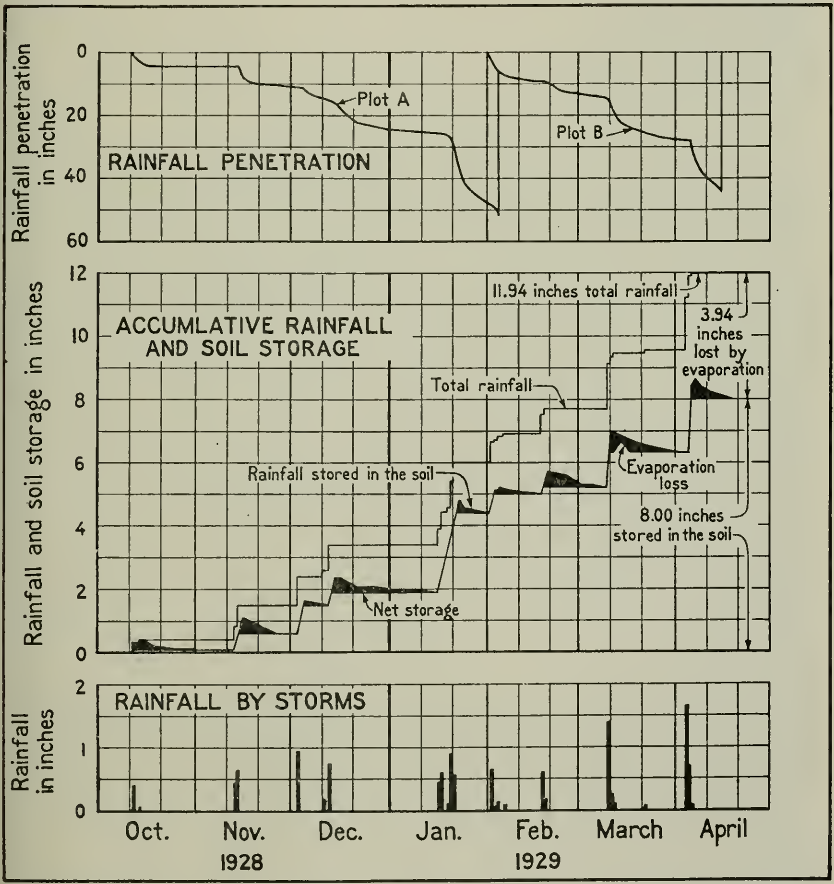
PLATE XXIV



EVAPORATION FROM BARE SOIL AFTER RAIN, ONTARIO.

Edison Avenue Plot.—Evaporation from the soil after each rain was measured in several ways throughout the season. One of the methods used was to select a plot 60 feet square on which the soil was dry to a considerable depth before the occurrence of rains in the fall. All plant growth was removed and the plot kept bare throughout the rainy season. A thorough sampling was made of the plot while it was still dry to obtain the initial moisture content. After each rain a trench twelve feet long and of required depth was dug and the wetted outline of rainfall penetration was noted. This was done daily for five days after each storm and then at less frequent intervals until the next storm. The trench was immediately refilled after the wetted outline was obtained and the face of the next day's trench was advanced six inches into undisturbed soil. Soil samples were taken in six-inch increments of depth at from five to seven points along the face of the trench. In other places soil tubes were used and five or seven holes put down to depths below the plane of rainfall penetration. Here, also, samples were taken in six-inch increments of depth. From the data thus

PLATE XXV



EVAPORATION OF RAIN FROM THE SOIL, EDISON AVENUE, ONTARIO, 1928–1929.

obtained the amount of rain stored in the soil was computed from day to day, and the difference between stored rain in the soil and total rainfall charged to evaporation.

After the rain had penetrated more than four feet into the soil, trenching became unduly laborious. Moreover, the probable error in computing the total stored rainfall in the soil increased as the penetration increased. To overcome these difficulties, a tract having an area of 800 square feet was roofed over in the fall before the rains started and this area was kept dry until the penetration in the soil not so covered was four feet deep. The roof then was removed and a new series of observations started from the ground surface. Data from this second plot were not used until the percolation had extended downward more than six inches.

Data from the two plots gave an accurate record of the evaporation from the soil under actual field conditions throughout the entire rainy season. Over 2500 soil samples were taken from the two plots during one season so as to reduce the experimental error as much as possible. The results are given in Plate XXV, which shows the rain by storms, the total rain, the outline of rainfall penetration in the soil, the amount of stored rain in the soil and the evaporation throughout the season. The evaporation after each storm is given in Table 63.

TABLE 63

EVAPORATION FROM BARE SOIL AFTER RAIN—EDISON AVENUE PLOT
Season of 1928-1929

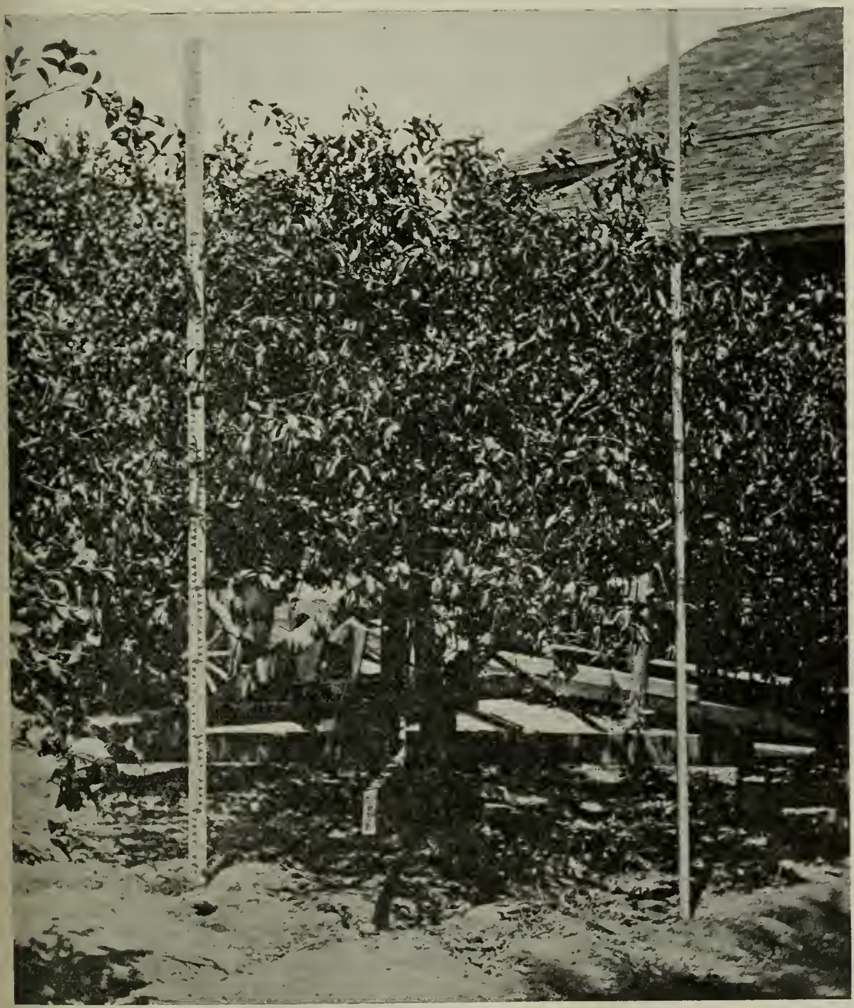
Date of storm	Rainfall in inches	Actual evaporation before next storm in inches
1928—		
October 13–14	0.40	0.30
November 13–15	1.10	.60
December 4	.93	.22
December 11–13	.95	.36
1929—		
January 16–17	1.05	----------
January 19–21	1.56	.11
February 2–4	.85	----------
February 7	.09	.29
February 19	.77	.57
March 10–12	1.79	----------
March 22	.08	.82
April 5–6	2.37	[1].67
Totals	11.94	[1]3.94

[1] To April 15.

Interception of Rain by Vegetation.—Interception by vegetation may be considered as one factor in the evaporation of rain. Citrus crops retain their foliage throughout the winter and intercept a certain portion of the rain before it reaches the ground. The amount of interception that may be expected was determined experimentally by weighing, sprinkling and reweighing a large lemon tree. The tree obtained for the test was 40 feet in circumference at the drip and twelve feet tall. Plate XXVI shows the tree as it appeared, somewhat wilted, eighteen hours after the start of the test.

The test was started on May 22, 1930. The tree was cut off at the base of the trunk at 7.00 p.m. and fitted with a base so that it could be set on a platform scale. At 7.50 p.m., the tree was weighed and then sprinkled for fifteen minutes with a fine spray and then weighed again. The amount of water held on the leaves, branches, and trunk of the tree was found to be equivalent to 0.04 inch depth over the area within the drip of the tree. The test was repeated at midnight and again at 4.00 a.m., and then seven other times until noon of May 23. After 7.00 a. m., each succeeding test was started as soon as the water from the preceding test had disappeared from the leaves. The tree did not appear wilted at 5.00 a. m., but the leaves drooped quickly after the sun's rays reached the tree and the tree did not regain its normal appearance even after continued sprinkling. The night was clear and calm until midnight, but a light east wind started shortly

PLATE XXVI



INTERCEPTION OF RAIN AS DETERMINED BY WEIGHING AND SPRINKLING A LEMON TREE. MAY, 1930.

after midnight, becoming brisk after 8.00 a.m. After the first test the tree did not again show as great an increase in weight in any of the succeeding tests, due in part to the branches and trunk being slightly wet when the succeeding tests were started.

7—81141

Results of Test No. 1.—

Weight of tree and support 50 minutes after cutting tree--462.0 pounds

Weight of tree and support immediately after sprinkling--490.0 pounds

Weight of tree and support after rapid dripping from leaves had ceased--------------------------------485.5 pounds

Weight of tree and support after shaking tree vigorously--480.5 pounds

In view of the above test, interception of rain on tree foliage was not considered of sufficient importance to warrant its consideration as a separate factor in the disposal of rain on the valley floors of this area. Interception and evaporation from the leaf surface is offset by the effect of shading the ground and reduction of evaporation from the shaded soil surface.

Summary of Winter Consumptive Use.—The detailed results of winter evaporation-transpiration studies have been given in previous chapters. With the exception of citrus, it has been very difficult to separate these two factors in rainfall disposal. In the Ebert plot A (citrus) the monthly winter transpiration use of water varied from 0.72 to 1.43 inches between November 1, 1928, and April 30, 1929, with an average of 1.05 inches per month. The average for the months of February, March and April in 1930 was 1.08 inches per month. Investigations have shown that bare lands and vineyards and deciduous orchards that are clean cultivated have no material transpiration loss during the winter period.

A summary of the average winter evaporation-transpiration rate per 30 days is given in Table 64, both for brush plots and for grass and weed plots. The average consumptive use of water for brush was 2.41 inches per 30 days, while that for grass and weeds was 2.07 inches per 30 days. These values, together with the average fall soil moisture deficiency, may be used in calculating the probable consumptive use for any year from the daily rainfall records.

TABLE 64

SUMMARY OF AVERAGE WINTER EVAPORATION-TRANSPIRATION RATE PER 30 DAYS FOR BRUSH AND GRASS AND WEED PLOTS

Plot	Crop	Period	Evaporation-transpiration losses in inches per 30 days
Muscoy I	Brush	October 25, 1927, to April 26, 1928	2.44
Muscoy I	Brush	October 12, 1928, to May 15, 1929	1.94
Muscoy J	Brush	October 25, 1927, to April 26, 1928	2.32
Muscoy J	Brush	October 12, 1928, to May 15, 1929	1.86
Palmer Canyon	Brush	January 5, 1930, to June 9, 1930	3.07
Station 76	Brush	October 25, 1927, to April 27, 1928	2.63
Station 76	Brush	October 12, 1928, to May 15, 1929	2.19
Claremont	Brush	January 5, 1930, to June 3, 1930	2.80
Average			2.41
A2	Grass and weeds	December 6, 1927, to April 14, 1928	2.37
D2	Grass and weeds	December 6, 1927, to April 17, 1928	1.40
E2	Grass and weeds	December 6, 1927, to April 17, 1928	2.05
F2	Grass and weeds	January 19, 1928, to April 11, 1928	2.41
G2	Vetch	December 23, 1927, to April 13, 1928	2.16
H2	Barley	December 24, 1927, to April 2, 1928	2.03
Average			2.07

The average maximum annual opportunity for consumptive use of water by brush of the valley floor may be estimated as follows:

The average initial fall moisture deficiency for the brush plots was 10.6 inches. The average winter rate of evaporation-transpiration was 2.4 inches per month. The normal distribution of rainfall is such that the full evaporation-transpiration opportunity is not met by the rains that come in October, November and April. This deficiency of rainfall is indicated to be 3.0 inches. With normal distribution of rainfall from October 1 to April 30, then, the average maximum annual opportunity for consumptive use is indicated to be 24.4 inches, computed as follows: $10.6+(7\times2.4)-3$.

However, direct deep penetration below the root zone occurs at any time when the total rain to that date has been sufficient to replenish the initial fall deficiency in soil moisture and the evaporation-transpiration demands up to that date. When the seasonal distribution of rain is such that the storms are concentrated within a period of four months, deep penetration may be expected after the total rain for the season passes 19.0 inches.

Daily rainfall records must be used in determining the annual consumptive use of water by brush and the yield to the underground water supply by direct deep penetration below the root zone, as the distribution of the storms is important. When the total seasonal rain is less than nineteen inches, it is usually entirely consumed by evaporation and transpiration on the brush covered areas of the valley floor. Penetration of rain to the ground water also may occur at any time when the intensity is high enough to cause local surface run-off to low spots. This factor, however, has been considered separately under the title "Run-off."

Soil Drainage With No Surface Evaporation or Transpiration.

Records from the 20-foot level in the Devil Canyon tunnel showed continued slow losses of soil moisture over periods of months. There were no roots present at any of the points of sampling and the losses could not be charged to air circulation in the tunnel as borings for samples were made through undisturbed soil to distances of five feet laterally from the sides of the tunnel.

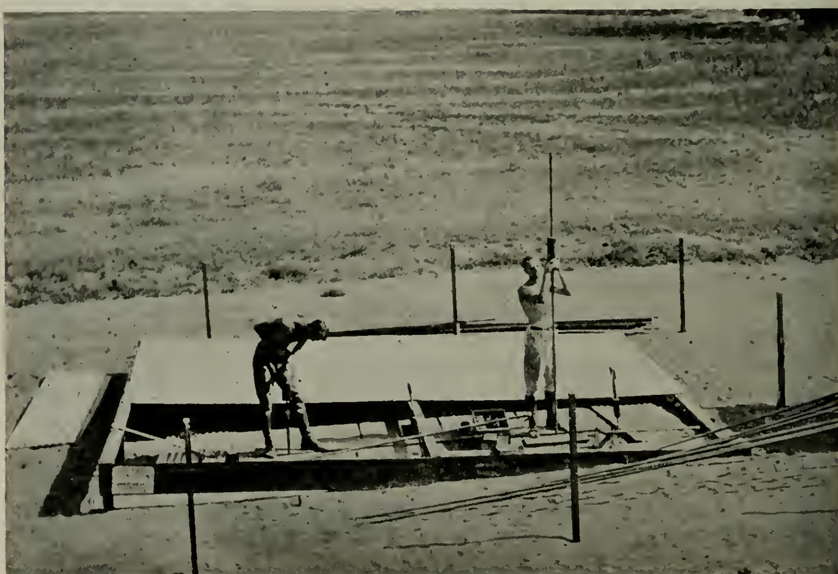
Edison Avenue Plot.—To check the rate and amount of soil moisture drainage that might occur in the soil below the root zone, soil drainage plots were established at Edison avenue, five miles south of Ontario. Starting in September, 1928, a plot 60 feet square has been kept entirely free of vegetation. From October 12, 1928, to April 6, 1929, 11.94 inches of rain fell on the plot. On June 18, 1929, a six-inch irrigation was applied to a 20-foot square area in the center of the clean cultivated plot. The center 144 square feet of the irrigated area was boarded over and sealed with roofing paper, and the entire 400 square feet covered with a corrugated iron roof. Plot A is shown in Plate XXVII. The movement of soil moisture under the sealed area, then, is entirely without the influence of transpiration or direct surface evaporation.

The moisture from the six-inch irrigation moved rapidly downward during the first few days after the water was applied. There also has been a continued slow movement of moisture, out of the top six feet of soil, extending over a period of fourteen months.

To make certain that this movement of soil moisture was downward, a second plot was established in January, 1930. This plot was set in a barley field that had a summer weed crop after the spring harvest of 1929. The soil was dry when the rains started in January, 1930. From January 6 to 12, 3.72 inches of rain fell on the plot and it then was covered and sealed in a manner similar to that employed in protecting the first plot.

Soil sampling under the sealed area is accomplished by boring through the roof with a wood auger and then using standard soil tubes to obtain soil samples. Each hole is backfilled and then resealed with tar and roofing paper.

PLATE XXVII



EDISON AVENUE SOIL DRAINAGE PLOT. AUGUST, 1929.

The soil moisture record from the two plots is given in Tables 65 and 66. All samples are being saved and moisture equivalent determinations will be made after the test is completed.

Evaporation From Water Surface.

Records of the evaporation from a free water surface are available at Ontario, San Bernardino, Riverside and Santa Ana. The type of pan at each location is the standard United States Weather Bureau Class A pan.

The Riverside record is kept by the Citrus Experiment Station of the University of California and covers a period from November, 1924, to date. The total annual evaporation at this station shows a range from a minimum of 64.33 inches recorded in 1927 to a maximum of 70.06 inches recorded in 1925.

TABLE 65

SOIL DRAINAGE WITH NO SURFACE EVAPORATION OR TRANSPIRATION

Covered Plot A—Edison Avenue, Ontario, 1929-30

Date	Moisture content of the soil (average of three holes)																	
	0.0 to 0.5 foot	0.5 to 1 foot	1 to 2 feet	2 to 3 feet	3 to 4 feet	4 to 5 feet	5 to 6 feet	6 to 7 feet	7 to 8 feet	8 to 9 feet	9 to 10 feet	10 to 11 feet	11 to 12 feet	12 to 13 feet	13 to 14 feet	14 to 15 feet	15 to 16 feet	16 to 17 feet	17 to 18 feet
	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent
1929—																			
June 17	2.2	4.2	5.6	6.1	6.4	7.8	12.5	13.0	20.7	23.9	19.3	12.9	6.8	7.6	16.1	14.4	2.8	7.6	12.7
June 18	Irrigate	d—six ac	re-inches	per acre															
June 19	12.5	10.8	11.8	12.0	11.0	7.6	11.2	13.9	19.7	24.5	19.1	12.1	8.3	7.3	13.9	21.6	3.2	8.3	12.6
June 20	10.2	8.6	9.9	10.6	11.3	11.5	11.8	13.9	18.9	24.9	21.7	13.2	8.8	7.5	14.7	18.9	3.6	8.0	13.7
June 21	8.3	8.5	8.8	9.5	11.2	13.3	13.7	13.3	21.3	25.5	20.5	13.0	8.7	7.9	14.7	19.8	3.0	8.1	13.3
June 22	8.5	8.0	8.5	9.2	10.6	13.1	14.8	14.7	19.8	22.7	20.9	11.9	7.6	7.9	14.6	17.6	3.3	7.5	14.5
June 23	7.9	7.5	8.1	8.4	9.9	12.8	15.6	14.4	17.3	24.7	22.1	13.5	7.4	8.3	12.8	19.4	3.3	6.0	15.6
June 24	8.0	7.4	8.0	8.7	9.8	12.2	15.4	14.2	19.5	25.6	21.6	12.7	8.0	7.3	18.8	18.2	2.8	7.6	14.3
June 25	7.8	7.0	7.6	8.3	9.5	12.2	14.4	14.4	18.1	21.3	21.7	12.0	8.1	8.0	14.1	15.4	3.0	6.4	14.6
June 26	7.9	7.6	7.9	8.1	9.3	11.8	14.5	14.6	19.9	24.1	20.8	12.2	8.2	7.7	15.0	17.2	2.8	6.7	14.3
June 28	7.3	7.4	7.6	8.0	9.1	11.6	14.6	14.3	21.6	23.6	20.3	13.1	7.7	8.0	15.1	19.5	3.2	8.5	14.5
July 1	6.5	7.5	7.3	7.7	8.6	11.2	14.6	15.8	21.8	24.2	20.3	13.0	7.8	8.3	16.7	[2]28.3	3.0	7.9	14.7
July 5	5.5	6.3	7.0	7.4	8.0	10.6	13.9	15.5	21.2	24.6	21.0	13.6	7.9	8.0	16.1	25.4	2.8	8.6	15.6
July 8	5.6	6.2	7.0	7.4	7.9	11.3	14.3	16.5	21.5	23.9	21.7	12.6	8.3	8.2	16.5	27.2	3.0	7.2	14.9
July 12	5.5	7.0	6.9	7.0	7.6	10.8	15.0	17.0	22.8	24.8	20.9	13.1	9.1	9.1	16.4	27.4	3.0	7.0	15.0
July 18	[1]7.4	6.6	6.9	7.2	7.5	10.4	13.7	15.5	23.5	26.4	24.3	14.9	8.9	9.0	16.3	29.3	2.9	9.4	12.6
August 17	6.5	6.0	6.2	6.4	6.5	8.0	11.2	12.5	23.2	24.9	20.6	14.6	9.3	9.9	15.9	26.3	3.1	10.3	13.7
August 28	6.6	5.9	6.2	6.4	6.5	8.0	11.4	14.6	22.0	24.4	21.7	14.6	9.2	11.0	18.1	28.9	2.9	9.3	14.2
September 27	6.3	5.6	5.9	6.1	6.2	8.3	12.3	14.8	20.8	25.8	20.5	15.3	10.2	12.8	20.5	30.1	2.8	9.3	14.4
October 26	6.4	5.5	5.8	6.1	6.0	7.2	11.6	14.5	22.0	26.8	24.5	14.8	9.7	12.0	17.4	30.8	2.8	8.2	11.4
December 2	5.8	5.2	5.7	5.8	5.7	7.4	11.6	13.4	23.2	26.4	22.1	13.5	8.7	11.5	17.6	31.5	2.9	8.6	13.2
1930—																			
January 7	6.2	5.5	5.6	5.7	5.6	7.8	11.3	14.2	21.5	25.8	23.7	14.5	8.6	11.5	17.6	28.7	3.0	10.7	13.6
May 3	6.2	5.5	5.4	5.5	5.4	7.9	11.6	13.5	23.9	26.9	23.0	14.5	10.2	13.7	21.2	31.8	2.7	6.3	15.0
August 27	5.5	5.2	5.1	5.2	5.2	7.4	12.0	13.8	21.9	27.2	24.6	16.3	11.4	17.8	24.6	33.4	3.0	7.6	13.6

[1] Sampled under corrugated iron roof six inches from edge of sealed cover, June 17 to July 12, and under sealed cover after July 12.
[2] Sand discarded from fifteen-foot sample from this date on.

TABLE 66

SOIL DRAINAGE WITH NO SURFACE EVAPORATION OR TRANSPIRATION

Covered Plot B—Edison Avenue, Ontario, 1930

Date of sample	Moisture content of the soil (average of six holes)																	
	0.0 to 0.5 foot	0.5 to 1 foot	1 to 1.5 feet	1.5 to 2 feet	2 to 2.5 feet	2.5 to 3 feet	3 to 3.5 feet	3.5 to 4 feet	4 to 4.5 feet	4.5 to 5 feet	5 to 5.5 feet	5.5 to 6 feet	6 to 6.5 feet	6.5 to 7 feet	7 to 7.5 feet	7.5 to 8 feet	8 to 8.5 feet	8.5 to 9 feet
	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent	In per cent
1930—																		
January 13	10.8	10.0	10.6	10.7	8.9	2.9	2.8	3.3	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
January 20	[1]8.4	--------	[2]8.5	--------	[3]9.1	--------	6.2	3.4	4.8	6.9	7.4	7.4	8.6	14.0	14.4	16.0	17.4	16.0
February 3	7.4	6.5	[2]7.4	--------	[3]7.9	--------	[4]6.6	--------	[5]5.9	--------	[6]7.4	--------	--------	--------	--------	--------	--------	--------
April 14	6.6	5.6	[2]6.1	--------	[3]6.5	--------	6.4	6.2	7.1	8.8	9.6	8.3	--------	--------	--------	--------	--------	--------
June 11	6.0	5.2	[2]5.8	--------	[3]6.1	--------	6.0	6.2	7.0	9.0	9.7	8.8	11.2	16.1	16.7	18.4	20.4	19.2
August 26	5.5	4.7	[2]5.3	--------	[3]5.6	--------	5.5	5.5	6.6	9.3	10.4	9.5	11.7	17.5	17.2	19.3	20.9	18.4

NOTE: From January 6 to 12, 3.72 inches of rain fell on the plot. The plot then was covered and sealed so that there was no further loss by surface evaporation or transpiration.

[1] Per cent in first foot of depth.
[2] Per cent between one and two feet in depth.
[3] Per cent between two and three feet in depth.
[4] Per cent between three and four feet in depth.
[5] Per cent between four and five feet in depth.
[6] Per cent between five and six feet in depth.

The stations at Ontario, San Bernardino and Santa Ana were established during the progress of this investigation. The variation between stations is small, as indicated by the records for the year July 1, 1929, to June 30, 1930, as follows:

Station	*Period*	*Evaporation in inches*
Ontario	July 1, 1929, to June 30, 1930	66.42
San Bernardino	July 1, 1929, to June 30, 1930	67.95
Riverside	July 1, 1929, to June 30, 1930	66.90
Santa Ana	July 1, 1929, to June 30, 1930	67.62

The maximum deviation from the mean reading at these four stations is 1.2 per cent. Table 67 gives the records from Ontario, San Bernardino and Santa Ana by months. The monthly record for the Riverside station is given in Table 68. Table 69 gives the weekly record for the Ontario station.

TABLE 67

EVAPORATION FROM WATER SURFACE—CLASS A WEATHER BUREAU TYPE OF PAN AT ONTARIO, SAN BERNARDINO AND SANTA ANA

Month	Ontario[1]			San Bernardino[2]		Santa Ana[2]	
	1928	1929	1930	1929	1930	1929	1930
	In inches	In inches	In inches	In inches	In inches	In inches	In inches
January	------------	1.87	1.51	------------	2.32	------------	2.28
February	------------	1.85	2.57	------------	3.46	------------	2.87
March	3.39	3.53	3.54	------------	5.02	------------	4.48
April	6.28	3.83	5.19	------------	5.38	------------	6.05
May	6.04	7.31	5.25	7.78	5.89	8.39	6.79
June	7.37	8.59	6.76	8.89	7.22	8.23	6.95
July	9.74	10.17	8.43	9.78	8.33	8.89	8.54
August	9.28	10.55	7.65	8.81	------------	8.90	------------
September	8.25	6.39	------------	5.69	------------	5.65	------------
October	4.44	6.21	------------	5.58	------------	6.06	------------
November	3.46	4.96	------------	4.98	------------	5.26	------------
December	1.96	3.32	------------	3.82	------------	3.44	------------

Total evaporation, July 1, 1929, to June 30, 1930—
Ontario ---------- 66.42 inches
San Bernardino ---------- 67.95 inches
Santa Ana ---------- 67.62 inches

[1]Observations by C. A. Taylor.
[2] Observations by A. A. Young.

TABLE 68

EVAPORATION FROM WATER SURFACE—CLASS A WEATHER BUREAU TYPE OF PAN AT CITRUS EXPERIMENT STATION, UNIVERSITY OF CALIFORNIA, RIVERSIDE[1]

Month	1924	1925	1926	1927	1928	1929	1930
	In inches	In inches	In inches	In inches	In inches	In inches	In inches
January	------------	3.558	4.422	1.199	2.538	2.406	1.755
February	------------	2.626	3.808	.935	4.503	2.384	2.206
March	------------	4.990	4.851	4.127	3.903	4.122	3.891
April	------------	5.282	4.570	3.999	6.731	4.593	5.437
May	------------	6.523	7.856	7.610	5.763	6.905	5.845
June	------------	8.402	7.437	7.596	7.590	8.611	7.684
July	------------	10.558	9.045	9.975	9.523	10.093	9.504
August	------------	9.518	9.317	10.302	9.441	9.970	------------
September	------------	7.152	7.003	7.227	7.739	5.405	------------
October	------------	3.470	5.899	5.620	4.705	5.526	------------
November	4.400	5.041	2.561	3.768	3.215	5.492	------------
December	3.362	2.937	1.888	1.975	2.827	3.598	------------
Totals	------------	70.057	68.657	64.333	68.478	69.105	------------

[1] Records furnished by Dr. L. D. Batchelor, Director, Citrus Experiment Station, University of California, Riverside.

TABLE 69

WEEKLY RECORD OF EVAPORATION FROM WATER SURFACE—CLASS A WEATHER BUREAU TYPE OF PAN AT ONTARIO

1928		1929		1930	
Week ending	Loss for week in inches	Week ending	Loss for week in inches	Week ending	Loss for week in inches
February 13	0.97	January 7	0.54	January 6	0.64
February 20	.81	January 14	.67	January 13	.17
February 27	.86	January 21	.18	January 20	.22
March 5	.62	January 28	.31	January 27	.36
March 12	.67	February 4	.29	February 3	.55
March 19	.93	February 11	.33	February 10	.70
March 26	.69	February 18	.47	February 17	.71
April 2	1.12	February 25	.62	February 24	.51
April 9	1.29	March 4	.86	March 3	.59
April 16	1.46	March 11	.71	March 10	.53
April 23	1.54	March 18	.71	March 17	.66
April 30	1.63	March 25	.66	March 24	.74
May 7	1.99	April 1	1.08	March 31	1.32
May 14	1.00	April 8	.81	April 7	1.04
May 21	1.04	April 15	.93	April 14	.93
May 28	1.39	April 22	.70	April 21	1.60
June 4	1.44	April 29	1.00	April 28	1.46
June 11	1.55	May 6	1.79	May 5	.36
June 18	1.88	May 13	1.84	May 12	1.08
June 25	1.64	May 20	1.65	May 19	1.11
July 2	2.08	May 27	1.02	May 26	1.88
July 9	2.00	June 3	2.11	June 2	1.43
July 16	2.36	June 10	1.61	June 9	1.75
July 23	2.34	June 17	1.71	June 16	1.32
July 30	2.19	June 24	2.56	June 23	1.42
August 6	1.77	July 1	2.15	June 30	1.82
August 13	2.22	July 8	2.23		
August 20	2.08	July 15	2.18		
August 27	2.20	July 22	2.58		
September 3	2.20	July 29	2.37		
September 10	2.26	August 5	2.15		
September 17	1.76	August 12	2.49		
September 24	2.00	August 19	2.36		
October 1	1.50	August 26	2.35		
October 8	1.29	September 2	2.28		
October 15	.87	September 9	1.35		
October 22	1.18	September 16	1.94		
October 29	.75	September 23	1.33		
November 5	.64	September 30	1.17		
November 12	.90	October 7	1.61		
November 19	.58	October 14	1.15		
November 26	1.10	October 21	.94		
December 3	.58	October 28	2.00		
December 10	.54	November 4	1.26		
December 17	.28	November 11	1.01		
December 24	.47	November 18	1.30		
December 31	.47	November 25	1.23		
		December 2	.81		
		December 9	.71		
		December 16	.52		
		December 23	.89		
		December 30	.98		

PART II

EVAPORATION AND TRANSPIRATION LOSSES FROM MOIST AREAS

CHAPTER I

GENERAL STATEMENT*

Introduction.

This progress report presents the results obtained in the first year's study of some of the ground water problems in the Santa Ana River Valley in southern California. Soil moisture studies carried on simultaneously by the Division of Agricultural Engineering in various parts of the Santa Ana River Basin were presented in Part I.

The original purposes of this study were to determine, by tank experiments, the evaporation from bare uncultivated fine sandy loam soils and the consumptive use of water by salt grass (Distichlis Spicata) and Bermuda grass (Cynodon Dactylon), where the water table is six feet or less beneath the ground surface. With these objects in view, equipment for two experiment stations was installed early in 1929. Because of differences in climatic conditions it was deemed advisable to divide the work at the outset between San Bernardino County, in the upper, and Orange County, in the lower Santa Ana basins, with the intention of installing the greater part of the equipment at the latter place.

The original plan has been extended from time to time and additional tank experiments now are being conducted to determine the consumptive use of water by tules, cat-tails, rushes and willows, but data obtained from only one tank of tules is now available, the other tanks having been installed too late to permit of the incorporation of the results obtained in this report. Investigations to determine the effect of oil films in preventing evaporation from water surfaces with a view to finding a means of preventing large evaporation losses from storage reservoirs, and studies of the surface, or perched water table of the Coastal Plain of Orange County by measurement of surface test wells throughout one dry and one wet season were carried on. Records were obtained of the rise of the perched water table due to rainfall, and the amount of precipitation which penetrated to the perched water table, increasing the underground drainage flow from a portion of the Newhope Drainage District, was measured.

Summary.

1. Data regarding evaporation from bare soils and transpiration from salt grass and Bermuda grass grown in tanks in which the water levels have been held at predetermined depths have been collected at experiment stations at Santa Ana and San Bernardino. From the data thus obtained the following conclusions have been reached:

* Part II was prepared by Harry F. Blaney, Irrigation Engineer, and A. A. Young, Assistant Irrigation Engineer, under the general supervision of W. W. McLaughlin, Associate Chief of Division of Agricultural Engineering, U. S. Department of Agriculture.

No evaporation occurred from bare surfaces of undisturbed fine sandy loam soil in tanks having a water level four feet below the soil surface. The monthly evaporation from the same tanks, but with the water level three feet below the surface, for the period from January 1 to April 30, 1930, inclusive, was less than 0.1 inch. For similar tanks having a two-foot water level, evaporation from bare soil averaged 0.75 inch per month during five summer months and 0.25 inch per month during four winter months. In tanks containing disturbed soil with a two-foot depth to the water table, soil evaporation ranged from 2.95 inches during August, 1929, to 0.73 inch in February, 1930, with a total of 14.58 inches from August, 1929, to April, 1930, inclusive. This is 3.5 times the evaporation recorded for the tanks containing undisturbed soil with the water table held at the two-foot depth for the same period.

Consumptive use of water by salt grass growing at the Santa Ana station in tanks having a two-foot water level varied from 5.64 inches in July, 1929, to a minimum of 0.72 inch in January, 1930, with a total of 35.3 inches for the twelve-month period, May, 1929, to April, 1930, inclusive. With a four-foot water level, a maximum loss of 2.96 inches occurred during August, 1929, a minimum loss of 0.31 inch during January, 1930, and a total use of 13.37 inches for the entire period.

At San Bernardino, Bermuda grass growing in tanks having a three-foot water level used a maximum of 5.49 inches during July, 1929, and a minimum of 0.66 inch in February, 1930, with a total of 32.53 inches for the twelve-month period ending April 30, 1930. In tanks having a two-foot water level, the maximum use of 6.51 inches occurred during July, 1929, and the minimum use of 0.45 inch during January, 1930, with a total use of 37.27 inches for the period.

2. Tules growing in submerged soil in a tank not under natural swamp conditions used a maximum of 28.38 inches of water in October, 1929, and a minimum of 1.86 inches in January, 1930, when the tops were dead. The total consumptive use from August, 1929, to April, 1930, inclusive, was 139.32 inches, and for the twelve-month period from August 1, 1929, to July 31, 1930, inclusive, was 213.56 inches.

3. Commercial hot water tanks were successfully used as Mariotte reservoir tanks for automatically supplying water to soil tanks at predetermined constant levels in determining losses by evaporation and transpiration. Great care is necessary to protect the tank against temperature changes. The Mariotte tank and connecting pipe system must be air tight since the smallest air leak into the system upsets the equilibrium of forces responsible for successful automatic operation. The Mariotte tanks at Santa Ana are buried in the ground and are less affected by temperature changes than those at San Bernardino, which are above ground but boxed in and protected by asbestos paper and shavings. An increase of three degrees in temperature at San Bernardino increased the value of the vapor pressure in the partial vacuum chamber of the tank enough to reduce the water level in the glass gauge one millimeter.

4. During wet weather, soil tanks were protected from rains in order that the soil moisture content within the tanks might remain unchanged. If rainfall is not allowed on tank surfaces and water consumed by evaporation or transpiration is supplied only by a water level held at a

constant level, the experiment is a laboratory one, and the data obtained are not entirely applicable to natural field conditions. On the other hand, if rainfall is allowed upon the tank surface, soil moisture conditions within the tank will be changed until evaporation or transpiration removes the excess moisture and the initial conditions of the experiment, which were to maintain a constant water level at a predetermined depth, will no longer exist. Each method seems open to objection, but during the past season that of covering all soil tanks was adopted as probably constituting the better plan.

5. Various tests were made with the view of preventing evaporation from water surfaces by the use of oil films. Several grades of cylinder oil were used without material success. A portion of the oil film disappeared from the tank surface either by evaporation of the more volatile oil substances or through absorption by the water upon which it floated. Effective prevention of evaporation lasted but a few days and at the end of six weeks all benefit due to the oil film had disappeared.

6. The ground water underlying much of the agricultural area of Orange County is divided by an impervious stratum into a perched water table a few feet below the ground surface and a deeper underground supply which formerly was of an artesian character. The perched water table is replenished each year by rainfall, surface irrigation and occasional floods. It is depleted by soil evaporation, transpiration and drainage run-off. Surface test wells show that the water table does not fluctuate greatly. The deep underground basin, which is the greatest source of irrigation supply, has been depleted during the past 20 years until only a small artesian area remains. Water levels in wells are dropping from year to year, and costs of pumping are increasing with increased lifts. The underground basin is replenished by deep penetration from stream channels and rainfall, underflow from surrounding hills, excess irrigation in areas where a perched water table does not exist and by overflow from occasional floods.

7. Penetration of rainfall through from six to eight feet of fine sandy loam, measured as increased drainage flow between January 1 and June 1, 1930, amounted to less than one-half an acre-inch per acre over an area of 1900 acres with a total rainfall for the season of 11.1 inches. Increases in flow resulted from rains of 0.5 inch or over, and decreases occurred between heavy rains and following light rains. No doubt a part of the rainfall unaccounted for eventually reached the water table by slow drainage. Measurements of drainage flow were discontinued at the beginning of the irrigation season.

CHAPTER II

EXPERIMENTS AT SANTA ANA AND SAN BERNARDINO STATIONS

Meteorological Conditions.

Orange County is about equally divided between the Coastal Plain, upon which intensive agriculture is practiced, and the mountainous area lying east and north and covered with chaparral and other forest growths. The Santa Ana River cuts through these mountains in a canyon twelve miles long, dividing the Santa Ana Valley into two parts, with Riverside and San Bernardino counties in the upper and Orange County in the lower basin.

Table 1 shows the monthly mean maximum, mean minimum and mean temperatures, the rainfall, and the total number of miles of wind per month at the San Bernardino and Santa Ana stations.

The prevailing wind throughout the entire basin is from the ocean. The cooled night air of the Mohave Desert, after being warmed by the sun, flows upward during the day and is replaced by cooler air blowing in from the coast. At times, however, the direction of the wind is reversed and blows from the desert down through Cajon Pass, in the San Bernardino Mountains, across the Wineville district and through the Santa Ana Canyon into Orange County. These northerly winds, locally termed "Santa Ana winds," while they are sometimes cold, are very often hot and dry. When hot winds occur, large increases in the use of water by plants are recorded at the Santa Ana Station. The San Bernardino Station is not in the direct line of the Santa Ana winds and hence is not greatly affected. One important modifying factor upon the climate of Orange County is the light fog frequently prevalent for several miles back from the coast. Many of these fogs occur only in the early morning, disappearing shortly after sunrise, but they also are sometimes continuous throughout a period of several days. The moister air of the foggy days reduces both evaporation and transpiration.

The precipitation which occurs during the cooler months is insufficient for intensively cultivated crops which must, therefore, depend upon irrigation to supply the deficiency. On the Coastal Plain the rainfall increases slightly toward the adjoining mountains, but the increase is small, except in the higher ranges. It is slightly larger at San Bernardino than at Santa Ana.

Tables 2 and 3 show the daily rainfall at the Santa Ana and San Bernardino stations, with the total precipitation for each storm throughout the season.

The relation between the amount of daily evaporation from the Weather Bureau pan (Tank No. 20) and ground Tank No. 16, at

Santa Ana, together with the daily maximum and minimum temperatures and the daily wind movement is shown on Plate I. In general, evaporation responds to both temperature and wind movement as is shown by corresponding peaks and valleys on the plate, but there are some exceptions. For example, the peak of the wind diagram on March 14, 1930, shows a total wind movement of 200 miles, whereas the usual movement is but 40 or 50 miles per 24 hours. The evaporation on the same day from both pan and tank shows a decrease. This decrease was caused by a heavy rain accompanying the high wind in consequence of which the air was so saturated with moisture that very little evaporation was possible.

TABLE 1

MONTHLY TEMPERATURES, RAINFALL AND MILES OF WIND MOVEMENT PER MONTH AT SANTA ANA AND SAN BERNARDINO STATIONS

Month	Temperature					Rainfall in inches	Wind movement at Weather Bureau evaporation pan in miles per month (A)[3]	Wind movement at soil tanks in miles per month (B)[4]	Ratio of B to A in per cent
	Mean maximum, in degrees Fahrenheit	Mean minimum, in degrees Fahrenheit	Mean, in degrees Fahrenheit	Maximum, in degrees Fahrenheit	Minimum, in degrees Fahrenheit				
Santa Ana Station									
1929—									
May[1]	74	51	63	91	41	0.03			
June	76	53	65	95	43	.11			
July	81	60	71	89	52				
August	85	60	73	96	51				
September	79	58	69	98	42	.35	1695	1452	85.7
October	80	52	66	101	36		1745	1416	81.1
November	77	41	59	91	33		1806	1431	79.2
December	72	41	57	86	30		1547	1093	70.7
1930—									
January	62	40	51	76	30	5.55	1743	1201	68.9
February	66	44	55	87	33	.55	1682	1180	70.2
March	68	46	57	89	33	2.99	2212	1582	71.5
April	72	47	60	88	39	.80	1970	1327	67.4
May	70	48	59	83	40	1.23	2228	1301	58.4
Total						11.61			
San Bernardino Station									
1929—									
May[2]	82	47	65	94	37				
June	88	50	69	108	39	0.12			
July	95	57	76	106	49				
August	98	60	79	106	51				
September	88	55	72	107	41	.53	1012		
October	85	46	66	98	31		1183		
November	80	34	57	91	26		1589		
December	75	33	54	85	25		1255		
1930—									
January	61	36	49	76	24	4.71	1434		
February	74	38	56	87	31	1.06	1357		
March	70	41	56	88	28	3.99	1864		
April	77	45	61	95	35	1.33	1143		
May	74	44	59	95	34	1.76	967		
Total						13.50			

[1] Beginning May 5, 1929.
[2] Beginning May 9, 1929.
[3] Anemometer twelve inches above evaporation pan.
[4] Anemometer twelve inches above soil tanks.

TABLE 2

DAILY RAINFALL AT SANTA ANA STATION WITH TOTALS FOR STORMS, 1929-30

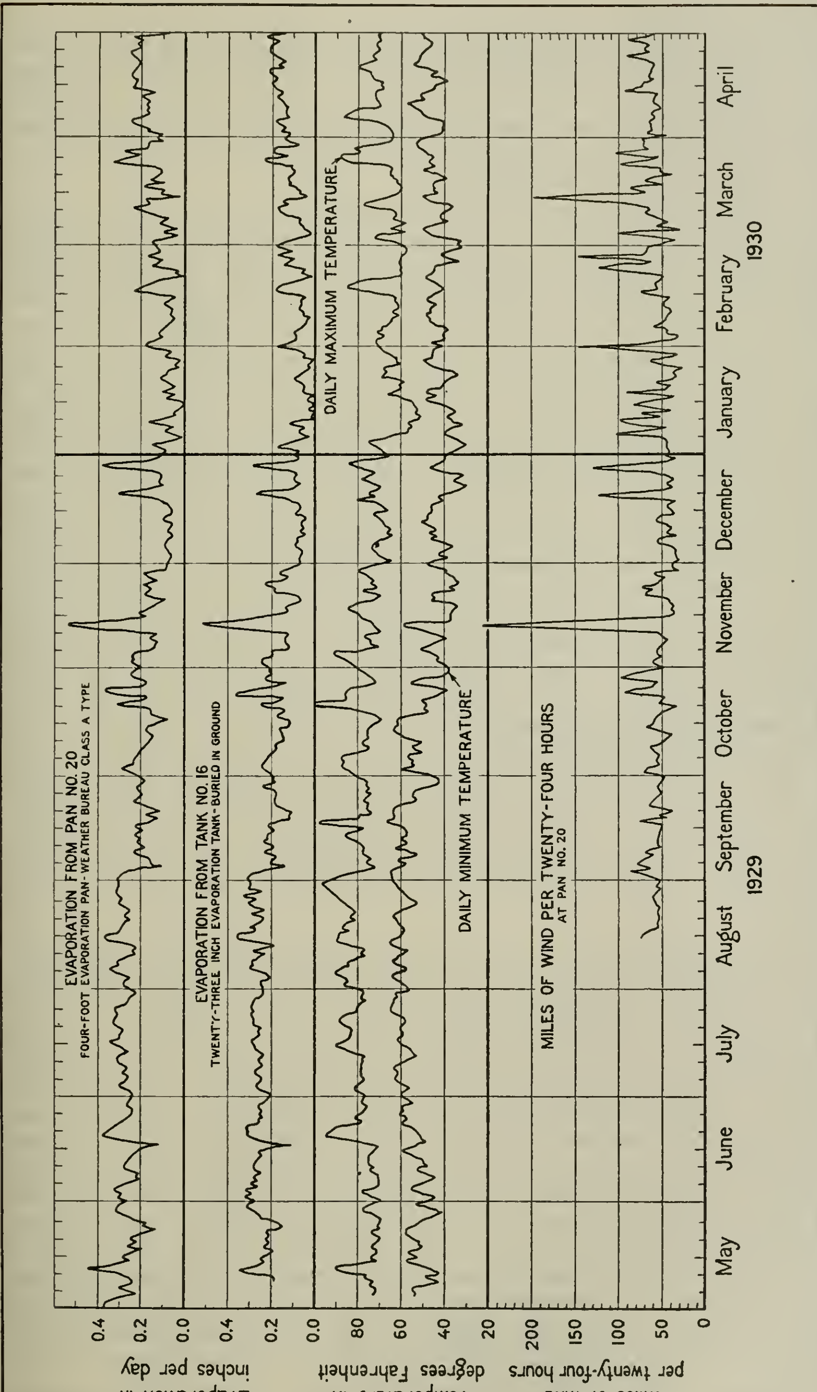
Date	Rainfall in inches		Date	Rainfall in inches	
	Day	Storm		Day	Storm
1929—			1930—		
May 24	0.03	0.03	February 22	0.40	0.45
June 16	.05	------------	February 26	.09	------------
June 17	.06	.11	February 27	.01	.10
September 4	.01	.01	March 3	.06	------------
September 16	.01	------------	March 4	.34	------------
September 18	.33	.34	March 5	.01	.41
			March 13	.07	------------
1930—			March 14	1.72	------------
January 5	0.59	------------	March 15	.62	------------
January 6	.21	------------	March 16	.07	------------
January 9	1.57	------------	March 18	.03	2.51
January 10	.93	------------	March 29	.07	.07
January 11	.10	------------	April 29	.28	------------
January 12	.28	------------	April 30	.52	------------
January 13	.14	------------	May 1	.05	------------
January 14	.96	------------	May 2	.06	------------
January 15	.20	------------	May 3	.40	------------
January 17	.08	------------	May 4	.68	1.99
January 19	.01	5.07	May 8	.02	.02
January 26	.34	------------	May 16	.02	.02
January 27	.14	.48			
February 20	.05	------------	Total	------------	11.61

TABLE 3

DAILY RAINFALL AT SAN BERNARDINO STATION WITH TOTALS FOR STORMS, 1929-30

Date	Rainfall in inches		Date	Rainfall in inches	
	Day	Storm		Day	Storm
1929—			1930—		
June 15	0.12	0.12	February 26	0.10	1.06
September 17	.48	------------	March 4	.46	------------
September 18	.02	.50	March 5	.02	.48
September 29	.03	.03	March 14	1.90	------------
			March 15	.25	------------
1930—			March 16	.24	2.39
January 5	0.18	------------	March 30	.45	------------
January 6	.19	------------	March 31	.67	1.12
January 8	.04	------------	April 13	.01	------------
January 9	.97	------------	April 14	.01	.02
January 10	.94	------------	April 28	.01	------------
January 11	.21	------------	April 29	.47	------------
January 12	.45	------------	April 30	.83	------------
January 13	.02	------------	May 1	.27	------------
January 14	.88	------------	May 2	.07	------------
January 15	.21	------------	May 3	.64	------------
January 17	.14	4.23	May 4	.56	2.85
January 26	.44	------------	May 8	.11	.11
January 27	.04	.48	May 17	.01	------------
February 19	.22	------------	May 18	.10	.11
February 22	.54	------------			
February 23	.20	------------	Total	------------	13.50

PLATE I



DAILY RECORDS OF EVAPORATION FROM WATER SURFACES, MAXIMUM AND MINIMUM TEMPERATURES AND WIND MOVEMENT, SANTA ANA STATION, 1929–1930.

8—81141

Santa Ana Station.

Description of Site.—The plot of ground selected as the site for the Santa Ana Experiment Station lies near the center of the Coastal Plain area of the county, about four miles west of Santa Ana on the Fifth Street road and one and one-half miles west of the Santa Ana River. The location is free from windbreaks and shade and is generally ideal for consumptive use of water studies.

The climatic conditions in Orange County vary slightly between the coast and the Puente Hills on the north and the Santa Ana Mountains on the east, the rainfall increasing somewhat toward the hills and the fog being more prevalent toward the coast. At the site selected, the climate is fairly representative for western Orange County in general.

The soil at the station is an alluvial soil classified as Hanford fine sandy loam, which grades into coarse yellow water bearing sand at a depth of six to seven feet.* It is probably lacking in humus and contains a small amount of alkali, but after a year's operation the surface deposits of alkali on soil evaporation tanks are not particularly serious.

Equipment Installed.—The equipment first installed consisted of twelve soil tanks, each connected with a Mariotte supply tank, a set of maximum and minimum thermometers and a thermograph set in a shelter house, a standard rain gage, a Weather Bureau type Class A evaporation pan, an evaporation tank of the same diameter as the soil tanks but 32 inches in depth, and a shallow well with a hand pump to supply water for the tanks. Later two Friez four-cup anemometers and three additional soil tanks were added, making fifteen tanks in all. Two additional tanks were installed for the study of the prevention of evaporation from water surfaces by the use of oil films and one tank for measuring the consumptive use of water by tules (Scirpus acutus). A small shelter house of galvanized iron, for housing tools and equipment, was erected in one corner of the station area. The plot itself is 50 by 100 feet and is surrounded by a tight wire fence, a driveway connecting it with the highway. Plate II shows the layout at the station.

The evaporation pan is set upon a wooden grillage in accordance with the directions issued by the Weather Bureau for pans of this type and a hook gage reading to thousandths of a foot is mounted on the side of the pan. At the northwest corner of the grillage one of the anemometers is mounted on a stand so that the level of the cups is about twelve inches above the pan and about 24 inches above the ground. Midway in the row of soil tanks is the second anemometer set twelve inches above the ground to record the mileage of air currents passing over the soil tanks. The records from the buried evaporation Tank No. 16 are for comparison with those for the evaporation pan and soil tanks. This tank also is used as a check tank in the study of prevention of evaporation by the use of oil films, being of the same size and having the same exposure as the oil film tanks. Evaporation from the buried tank is somewhat less than that from the evaporation pan, since, by reason of its greater exposure, the pan becomes warmer during the day and is more affected by wind than the buried tank.

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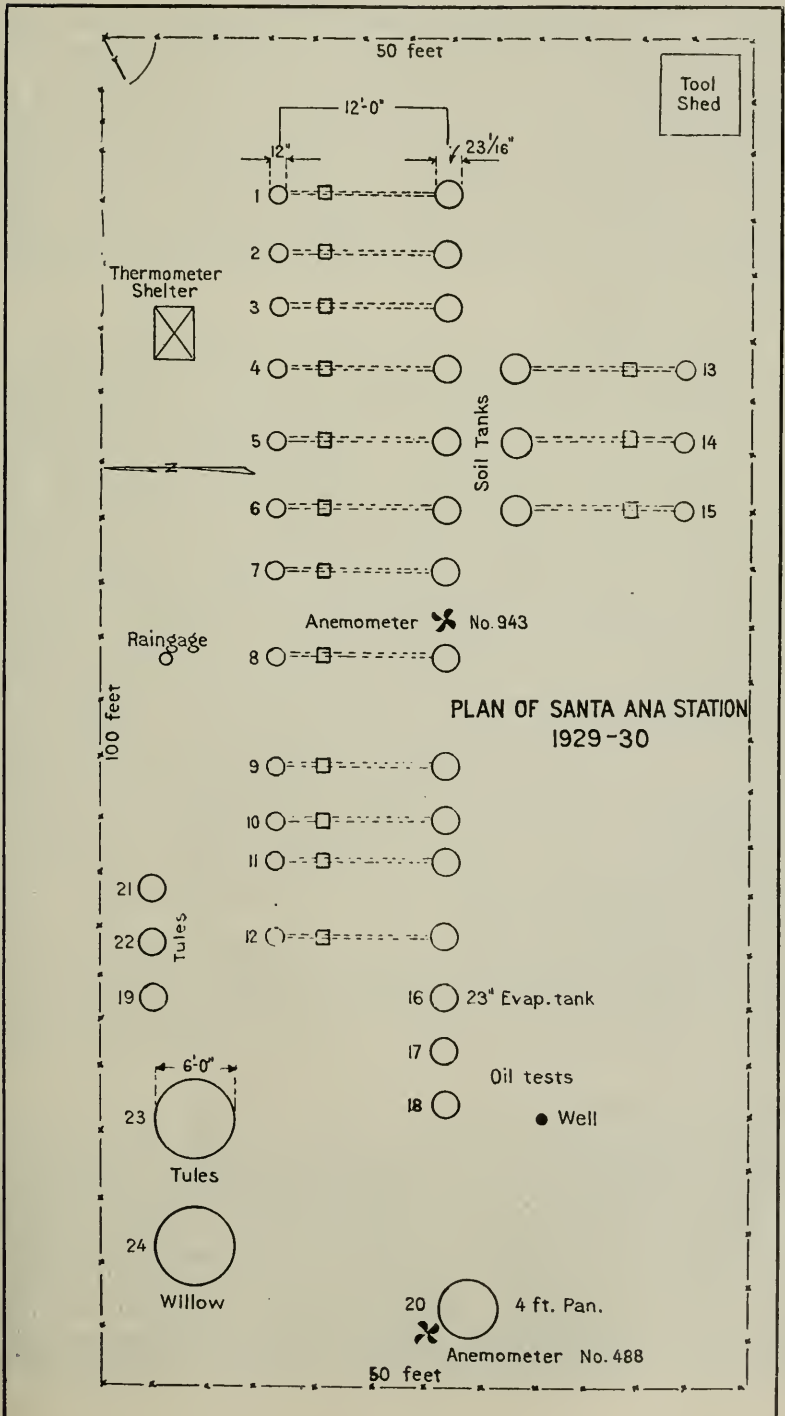
* Soil survey of the Anaheim area, California, Bureau of Soils, U. S. Department of Agriculture.

PLATE II


50 feet
Tool Shed
12'-0"
12"
23⁄16"
Thermometer Shelter
Soil Tanks
Anemometer No. 943
Raingage
100 feet
PLAN OF SANTA ANA STATION 1929-30
Tules
16 23" Evap. tank
17
Oil tests
18
Well
23 Tules
6'-0"
24 Willow
20 4 ft. Pan.
Anemometer No. 488
50 feet

In the spring of 1930 it was decided to extend the study of the use of water by moist area growths, which had been begun in the summer of 1929, by the installation of one tank containing the common swamp tule (Scirpus acutus). Consequently one tank was provided with the ordinary cat-tail (Typha) and another with triangular stemmed tule (Scirpus Americanus). Both tanks are 25½ inches in diameter by three feet deep. A third new tank six feet in diameter and three feet deep was planted to the same variety of tule as was already growing in Tank No. 19. In another six-foot tank a growing clump of willow (Salix lasiolepis) was planted. Because of the late start of the recently inaugurated work no results are available therefrom for this report.

San Bernardino Station.

In choosing a site for tank experiments near San Bernardino the use of a small plot at the Antil Pumping Plant of the San Bernardino Water Department was offered by the superintendent, William Starke, and, after a study of the vicinity, the offer was accepted. The location is one mile east of San Bernardino on low land overlying an artesian area. The station is supplied with water from the city pumps. The ground water is high and fluctuates with the season, ranging from two and one-half to six feet below the ground surface. Because of the high water table it was realized that the cost of setting deep tanks at this station would be high and for this reason the soil tanks which originally were six feet deep were cut down to a depth of 40 inches. Four tanks only were used. Additional equipment consists of maximum and minimum thermometers in a shelter, a Weather Bureau Class A evaporation pan, a Friez four-cup anemometer mounted upon the support for the pan, an evaporation tank of the same diameter as the soil tanks, a standard rain gage and a buried tank filled with soil covered with Bermuda grass. This tank has the same diameter as the four soil tanks and evaporation tank, but has a depth of only 30 inches. It was used in measuring the use of water by Bermuda grass when the grass was submerged under one or two inches of water. During the winter of 1929 the Bermuda grass was removed and tules planted for a test to begin in the following spring.

Each of the four soil tanks contained a vigorous growth of Bermuda grass with which the field was covered, the original root systems remaining in the undisturbed soil in the tanks, thereby giving a strong, well developed plant from the beginning. The soil is classified as a Chino silt loam.

Methods Used in Filling Soil Tanks.

The first equipment installed at the Santa Ana Station consisted of twelve soil tanks $23\frac{1}{16}$ inches in diameter and six feet deep, each unit consisting of a cylindrical water-tight outside tank, a heavy angle iron rim around the top of the inner tank supporting its weight upon the top of the outer. All sheet material is sixteen gage galvanized iron. The bottom plate is reinforced with two angle irons and is bolted in place by four threaded rods extending through the bottom plate angle irons to the supporting angle iron rim at the top of the tank. The inner tank is filled with soil and the outer with water, which passes into the soil through perforations in the removable bottom and in the wall of the inner tank, three inches above its bottom edge.

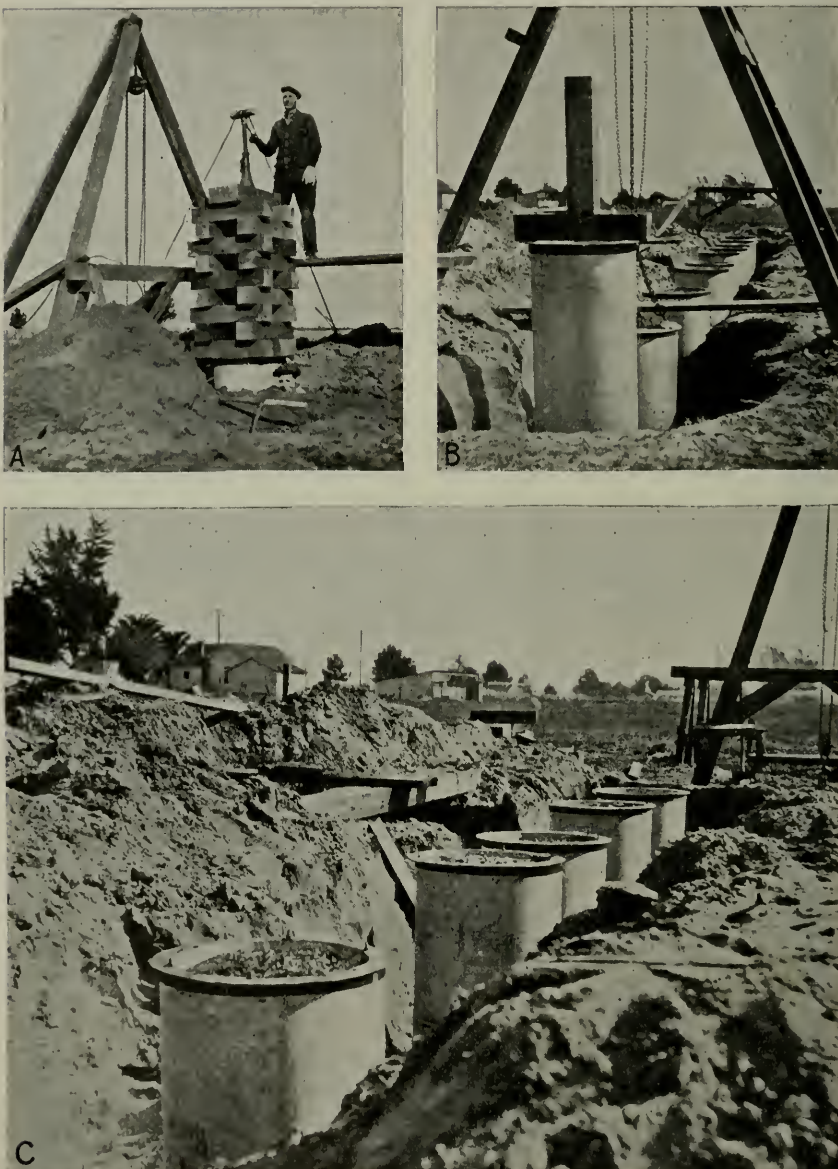
Heretofore, the general method of filling soil moisture tanks has been to keep separate the one-foot layers of soil as excavated from a trench and place it in the tank in the same order as orignally found in the ground. This process broke up the soil structure, increased the volume and changed the density. If tamped into the tank, alternate layers of loose and dense material resulted, with structural arrangements of soil particles entirely different from those it had orignally. Soil moisture experiments with soil thus placed have not always proved satisfactory. To rectify this condition the twelve tanks at Santa Ana and the four at San Bernardino were filled without materially changing the original soil structure. The plan followed was to fill each tank by forcing the bottomless inner shell into the ground at the point selected, cutting a core of soil of the full diameter of the tank to the full six-foot depth of the tank, and at the same time excavating about the shell as described later.

At first for forcing the tank into the ground use was made of a heavy screw jack resting upon a crib of timber blocks which in turn rested upon the heavy angle iron rim, the jack working against an overhead cable anchored in the ground on opposite sides of the excavation. This system is shown on Plate III A. As the tank sank into the soil under the action of the jack a gradually increasing pile of cribbing was used to support the jack against the cable. Eventually, the six-foot height of the tank, as it rested upon the ground surface in the beginning, was replaced by a timber crib of the same height. The anchors to which the cable was fastened were of a type used by telephone and electric light companies for anchoring guy wires and were quickly installed in holes bored with a six-inch soil auger.

To relieve outside friction on the side of the tank as it was forced downward, an excavation was made around it, care being taken to excavate so as not to undercut the cutting edge. This excavation usually kept a few inches ahead of the edge cutting out a core slightly larger than the diameter of the tank, it being found that this method speeded up the whole operation. As the tank was forced downward the skin friction on the inside of the soil column rapidly increased. In two attempts this friction was sufficient to stop the soil from rising above five feet in the shell. These two tanks were emptied and sunk again in new locations.

After the first two or three tanks had been filled it was found that the tank shell would slide over the core of soil if a sharp impact was given at the top of the timber crib, using a short piece of timber as a pile driver as shown in Plate III B. With one man working the jack and another jarring the top of the cribbing the process of sinking the tank was speeded up considerably. The force used in driving the tank shell over the soil column gradually changed from that applied by the jack alone to the use of both jack and pile driver impact until finally the jack was abondoned entirely in favor of driving by impact only, the last two or three tanks being installed in this way and saving the time required for setting the cable anchors. This method of sinking also had a tendency to decrease any soil compression as the

PLATE III



PLACING SOIL TANKS AT SANTA ANA STATION.

A. Cribbing and Jack Forcing Tanks Six Feet Into the Ground, 1928.
B. Soil Tanks Before Backfilling and Timbers Used in Driving Tanks by Impact, 1929.
C. Soil Tanks in Trench Before Backfilling, 1929.

sharp jar applied at the top broke the bond of the soil column against the metal wall and more rapid progress was possible. Plates III and IV show various stages in the operation of tank filling.

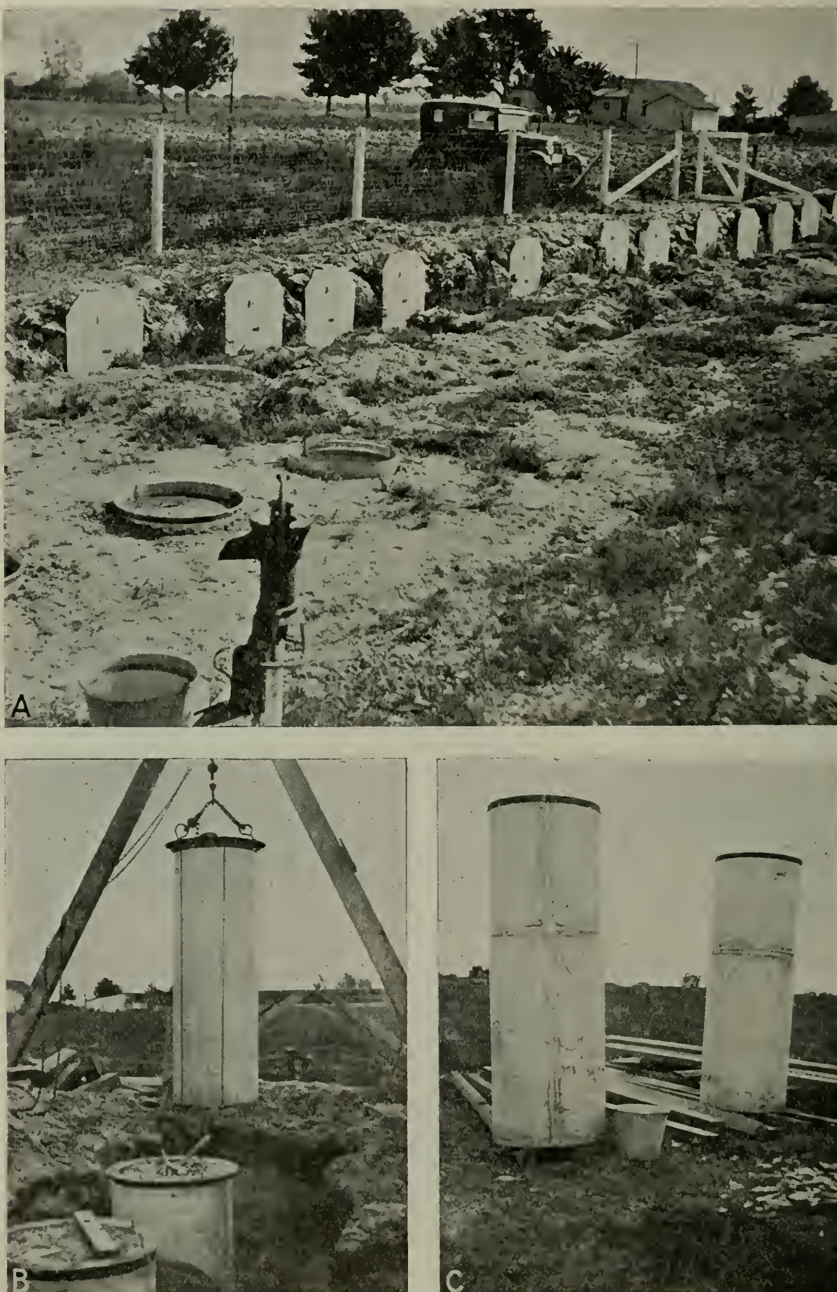
After the inner shell had been satisfactorily sunk, the bottom of the soil column was cut off by jacking the bottom plate across the bottom of the tank and bolting it to the angle iron rim at the top. The whole was then hoisted above ground by a chain block attached to a tripod. The outer shell then was set in the excavation and the inner shell with its soil content lowered into the outer until it hung suspended from the angle iron rim around the top.

As a means of comparing results of evaporation from similar soils placed in tanks by different methods, three tanks of the same size as those just described were filled with loose soil from an excavation near Tank Nos. 4, 5 and 6, the tanks to be used in the comparison. In making this excavation each foot of soil taken out was kept separate from the rest until there were six piles, each pile representing a depth of one foot. The three tanks were set in the excavation and partly backfilled to hold them in position. In filling the tanks all soil used was first passed through a quarter-inch screen to keep out coarse material. Soil from the pile representing the sixth foot was then placed in the bottom of each tank to a depth of thirteen inches, the extra inch being allowed for settlement, and each additional foot was filled in like manner except the top foot. Before this was filled the upper part of the tank was flooded with water to settle and compact the material as uniformly as possible. Water was added from time to time until it drained from the bottom of the tank through a pipe connection. The resulting settlement of the soil amounted very closely to the inch per foot allowed. The top foot then was similarly filled and flooded. Very little settlement has since taken place and there is no doubt as to this method producing a more uniform settlement and density than the tamping of soil placed in layers. At present a comparison of the results of evaporation from the two sets of tanks, one filled with disturbed soil and the other with soil undisturbed, shows a materially greater evaporation from the disturbed and flooded soil.

Operation of Soil Tanks.

Santa Ana Station.—That average results in measuring evaporation from bare soil and consumptive use of water by salt grass might be obtained, all tanks at the Santa Ana Station were operated in sets, each comprising three tanks having as nearly as possible identical conditions as to method of filling with soil, condition of surface and depth to water table. At San Bernardino, where there are only four tanks in use, the tanks were operated in pairs. In excavating around the soil tanks at the Santa Ana Station, as they were being filled, it was found that, although the upper fifteen inches of soil was moist from previous rains, the soil from fifteen to thirty inches below the surface was very dry. It was quite evident that the rainfall of approximately five inches of the preceding four months had penetrated only to a depth of fifteen inches. The lower limit of this dry zone was the upper limit of the moisture extending above ground water found at a depth of six to seven feet. The dry zone, therefore, was bounded by the lower

PLATE IV



SOIL TANKS AT SANTA ANA STATION, 1929.

A. Board Fronts with Doorways to Buried Mariotte Tanks; Soil and Evaporation Tanks in the Foreground.

B. Inner Shell of Soil Tank Showing Rods Supporting Bottom Plate.

C. Outer Shells of Soil Tanks, Six Feet Deep.

limit of rainfall penetration and the upper limit of the capillary fringe above the water table.

It was concluded that the limit of capillary rise in the Hanford fine sandy loam soil with which the tanks were filled was about four feet and this measure, therefore, was adopted as the depth to the lowest water table to be maintained in the soil tanks. Of the twelve tanks originally installed six have bare, uncultivated surfaces and the rest are covered with a growth of salt grass sod. Three of the bare tanks and three of the sod-covered tanks originally had a depth to water of four feet, while in the others the depth was two feet. In the three tanks installed in July, 1929, and filled with loose soil in order to observe the influence of the method of filling upon the soil evaporation, the surface has been kept bare of vegetation and the water table held at a depth of two feet. At San Bernardino the first pair of tanks has a water table at a depth of three feet and the second at two feet. All four are covered with a good growth of Bermuda grass.

Table 4 shows each tank's number, dimensions, date installed, condition of soil surface and depth to water table.

TABLE 4

INSTALLATION DATA ON TANKS USED AT SANTA ANA AND SAN BERNARDINO STATIONS

Tank number	Size of tank		Date installed	Nature of surface	Depth to water table in feet
	Diameter in inches	Depth in feet			
Santa Ana Station					
1-2-3	23 1-16	6.00	February, 1929	Bare, uncultivated, undisturbed soil	[1] 4 and 3
4-5-6	23 1-16	6.00	February, 1929	Bare, uncultivated, undisturbed soil	2
7-8-9	23 1-16	6.00	February, 1929	Salt grass sod, undisturbed soil	2
10-11-12	23 1-16	6.00	February, 1929	Salt grass sod, undisturbed soil	4
13-14-15	23 1-16	6.00	July, 1929	Bare, uncultivated, disturbed soil	2
16	23 1-16	2.70	April, 1929	Free water surface	
17	23 1-16	2.50	July, 1929	Water covered with oil film	
18	25 1-16	2.50	July, 1929	Water covered with oil film	
19	25 1-2	2.70	July, 1929	Tules standing in water	
20	48	0.83	April, 1929	Free water surface	
San Bernardino Station					
1-2	23 1-16	3.30	March, 1929	Bermuda grass sod, undisturbed soil	3
3-4	23 1-16	3.30	March, 1929	Bermuda grass sod, undisturbed soil	2
5	23 1-16	2.70	March, 1929	Free water surface	
6	23 1-16	2.70	March, 1929	Bermuda grass standing in two inches of water	
7	48	0.83	March, 1929	Free water surface	

[1] Water table raised from four to three feet below surface, October 1, 1929.

After a preliminary period of adjustment, permanent records were begun May 1, 1929, at Santa Ana and May 6, 1929, at San Bernardino. It soon was observed that Tank Nos. 1, 2 and 3 at Santa Ana did not lose any water by evaporation from the soil, thus supporting the conclusion made at the outset that the limit of the capillary fringe did not exceed four feet. In this case it was found to be somewhat less. During the spring of 1929 all tanks were left unprotected from rainfall, although what rain there was fell prior to the beginning of permanent records. After a heavy rain in April soil moisture extended down to the water table, but the surface did not continue moist enough to cause any evaporation during the following month.

On October 1, the water table was raised from four to three feet and one set of soil samples was taken in Tank No. 3 to determine the distribution of moisture in the soil. It was found that the top foot contained but 3.5 per cent of moisture, and that from the surface to the water table the percentage increased at a fairly uniform rate. The percentages are shown in Table 5.

TABLE 5

DISTRIBUTION OF SOIL MOISTURE IN TANK No. 3, SEPTEMBER 25, 1929, SANTA ANA STATION

Depth below soil surface in inches	Moisture content in per cent
0– 6	3.1
6–12	3.7
12–18	7.1
18–24	12.4
24–30	18.4
30–36	19.2
36–48	28.7

Since the moisture contents of the first and second six-inch sections were nearly the same it was evident that the water table must be raised at least one foot to permit evaporation to take place to an appreciable degree. After the change was made on October 1, water was drawn from the supply tank rather rapidly for a time, but it is thought that most of this served to increase the soil storage instead of being lost by evaporation. The loss was greatest during the first few days after the change was made and decreased rapidly during the next three weeks and thereafter the rate continued to decrease until February.

Tank Nos. 4, 5 and 6, filled with undisturbed soil, were operated with bare, uncultivated surfaces, with the water table at a depth of two feet. All three show slight indications of alkali. The highest weekly loss for the year occurred a few weeks after the tanks were filled, and a part of this loss should be charged to soil storage.

The third set, Tank Nos 7, 8 and 9, was operated with a two-foot water table, but with salt grass sod instead of bare surfaces. Tank No. 9 was the only one to have an original crop of grass at the outset. In this tank the grass root system was fully developed and remained undisturbed, except where the shell of the tank cut off lateral roots as it was forced into the ground. The other two tanks were bare and it was necessary to transplant grass and develop root systems in them before the maximum use of water was attained. A small amount of water was used on the surface to get the plants started. There was a continued increase in the use of water during May and June when the root systems were developing, a maximum use during July and August, and decreasing amounts until the following spring. The transplanted grass shows a very heavy and healthy growth of six inches or more in height. Tank No. 9, on the other hand, has a heavy mat of short stemmed grass which never has been luxuriant. Although this tank presents the appearance of having the poorest crop, the total amount of water used during the year from May, 1929, to May, 1930, exceeds that used in each of the other two tanks. This may be due to there having been a developed root system in this tank to start with.

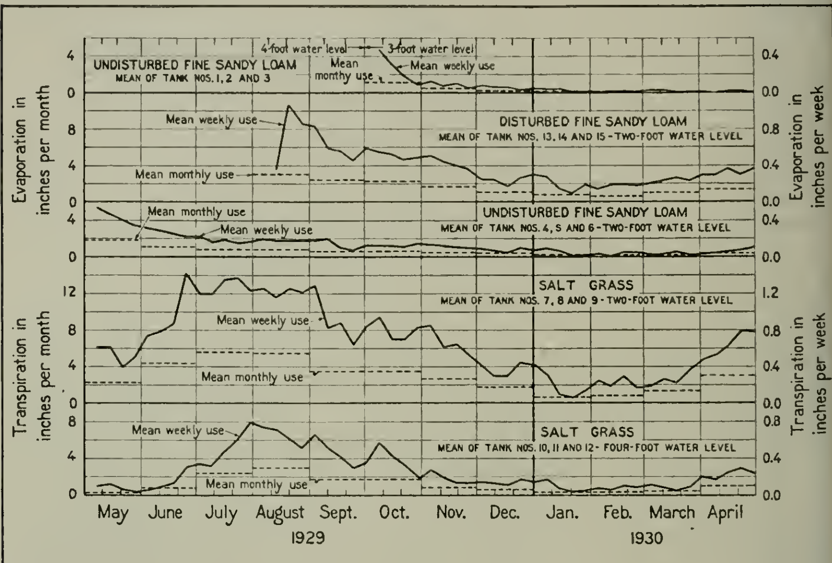
Tank Nos. 10, 11 and 12, comprising the fourth set, had a water table at a depth of four feet and were covered with the original salt grass sod found growing upon the surface when the tanks were installed and therefore had a fully developed root system in each tank from the beginning. The results from this set were somewhat irregular, which may have been partly due to irregularities in the Mariotte system. The salt grass growth on the tanks was sparse and dry in comparison with the grass in the tanks of the previous set.

Tank Nos. 13, 14 and 15 were installed in July, 1929, for the purpose of comparing the evaporation from tanks filled by different methods, the comparison to be made with Tank Nos 4, 5 and 6, previously described. Each set of tanks had the same depth to water, the same bare surfaces and contained the same type of soil, but Tank Nos. 4, 5 and 6 contained soil in its original undisturbed state while Tank Nos. 13, 14 and 15 were loosely filled. The records to date show about three and one-half times greater evaporation from the loosely filled tanks than from those in which the soil is undisturbed. With all other conditions equal it must, therefore, be concluded that the rearrangement of soil particles, which took place when the tanks were filled with loose soil, has a noticeable effect upon the capillary action and, therefore, upon evaporation from the soil surface. As tank experiments of evaporation from soil in the past have been conducted with loose material, or at least with material rearranged in structure when placed in the tanks, the question arises whether the results previously obtained are not too large for application to natural field conditions.

Each of the three tanks appears moist upon the surface in contrast to the dry appearance of the other bare tanks and are partly covered with alkali, which probably has some effect on the rate of evaporation. It was expected that tanks operated under similar conditions would not act alike in the amount of water used, because of differences in the soil, and consequently each test was run in triplicate. The results of a year's investigations have been as anticipated, as it has been found that no two tanks in the same set used the same amount of water. It also was found that the relation between the tanks of the set was fairly constant; *i. e.*, any tank using either more or less water in any one month than another tank in the same set would generally use water in about the same ratio in any other month. Exceptions occurred frequently, but it is thought difficulties of Mariotte operation may account for them. In Plate V the mean results recorded at Santa Ana from each set of three tanks have been plotted to show the mean weekly and mean monthly uses of water by each set. This gives a comparison of the amount evaporated from bare tanks with water tables at two, three and four feet in depth, and shows the increase in evaporation from disturbed soil over that from undisturbed soil. It also shows the mean weekly and monthly transpiration loss from salt grass with water tables at two and four feet in depth. Table 6 shows the weekly evaporation from soil and water surfaces and weekly use of water by salt grass and tules in tanks.

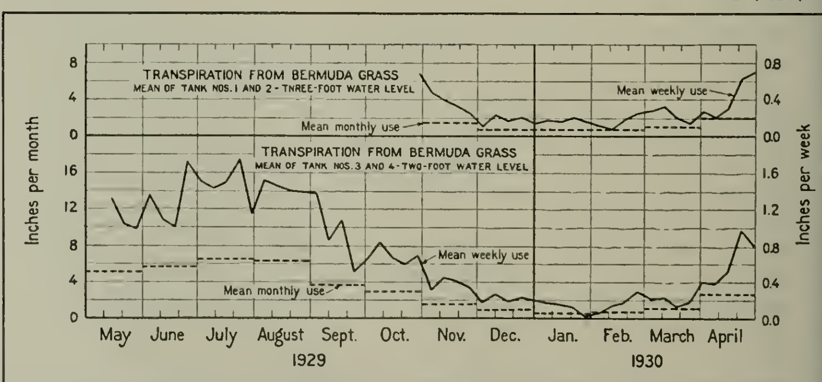
San Bernardino Station.—At the San Bernardino station, located at the Antil plant of the San Bernardino Water Department, four tanks operated in pairs are filled with undisturbed Chino silt loam and all contain the original Bermuda grass cover. The soil tanks are connected to Mariotte supply tanks.

PLATE V



MEAN WEEKLY AND MONTHLY USE OF WATER BY TANKS 1 TO 15, INCLUSIVE, SANTA ANA STATION, 1929–1930.

PLATE VI



MEAN WEEKLY AND MONTHLY USE OF WATER BY TANKS 1 TO 4, INCLUSIVE, SAN BERNARDINO STATION, 1929–1930.

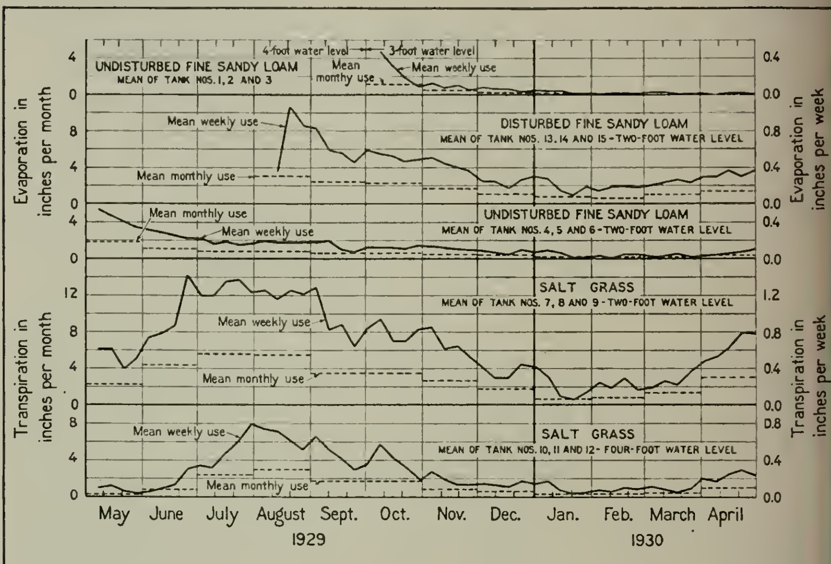
Tank Nos. 1 and 2 at this station maintain a soil water level three feet below the surface and Tank Nos. 3 and 4 have a two-foot water level. Tank No. 2 has given some trouble in operation and so many of the records relating thereto are so unreliable that much of the season's work has been omitted from the final results.

ES, MAY, 1929, TO MAY, 1930, IN TANKS AT SANTA ANA

12	Mean	13	14	15	Mean	16	19	20
0.180	0.095	----------	----------	----------	----------	----------	----------	2.064
.277	.117	----------	----------	----------	----------	1.716	----------	2.160
.127	.060	----------	----------	----------	----------	1.488	----------	1.740
.096	.042	----------	----------	----------	----------	1.518	----------	1.554
.097	.057	----------	----------	----------	----------	2.016	----------	2.124
.179	.088	----------	----------	----------	----------	1.896	----------	1.776
.234	.138	----------	----------	----------	----------	1.622	----------	1.694
.519	.311	----------	----------	----------	----------	1.932	----------	2.256
.482	.344	----------	----------	----------	----------	1.728	----------	1.752
.366	.315	----------	----------	----------	----------	1.836	----------	1.920
.587	.482	----------	----------	----------	----------	1.872	----------	2.196
.636	.621	----------	----------	----------	----------	1.920	----------	2.124
.823	.790	----------	----------	----------	----------	1.896	----------	1.932
.944	.742	----------	----------	----------	----------	1.728	3.827	1.968
.870	.716	0.254	0.449	0.353	0.352	1.692	4.107	1.812
.373	.620	.848	.866	1.465	1.060	2.100	5.400	2.160
.561	.518	.542	.824	1.197	.854	1.920	5.850	1.944
.689	.657	.392	.738	1.336	.822	1.942	7.324	2.026
.625	.512	.488	.514	.749	.584	1.332	4.951	1.188
.276	.419	.552	.450	.685	.562	1.396	6.190	1.408
.270	.295	.318	.524	.546	.463	1.080	4.838	1.116
.515	.352	.531	.479	.748	.586	1.344	6.188	1.380
.737	.574	.572	.372	.696	.547	1.416	7.284	1.620
.646	.431	.499	.502	.588	.530	1.020	4.894	1.092
.487	.326	.490	.385	.546	.474	1.092	5.738	1.092
.343	.188	.403	.438	.641	.494	1.524	7.651	1.632
.123	.278	.511	.417	.600	.509	1.344	7.427	1.500
.021	.186	.435	.385	.492	.437	1.416	6.526	1.464
.000	.139	.403	.309	.491	.401	1.032	4.952	1.236
.000	.139	.371	.310	.395	.359	1.080	4.388	1.008
.036	.148	.295	.245	.197	.246	.600	2.700	.636
.070	.131	.159	.266	.324	.250	.504	2.247	.540
.022	.109	.128	.246	.175	.183	.492	1.911	.492
.222	.172	.211	.192	.386	.263	.948	3.261	1.004
.117	.136	.286	.267	.363	.305	.912	3.037	1.188
.095	.169	.272	.287	.277	.279	.636	.636	.612
.063	.063	.137	.234	.085	.152	.252	.252	.408
.010	.021	.063	.140	.097	.100	.300	.300	.456
.011	.039	.137	.288	.160	.195	.336	.336	.480
.010	.067	.042	.235	.160	.146	.720	.871	.852
.000	.046	.106	.277	.181	.188	.336	.588	.492
.032	.095	.126	.211	.256	.198	.708	1.152	.876
.010	.081	.148	.171	.255	.191	.552	.730	.552
.021	.105	.169	.265	.203	.212	.708	1.035	.820
.000	.081	.181	.203	.331	.238	.744	.984	.924
.000	.046	.203	.448	.159	.270	.684	.948	.840
.074	.091	.192	.320	.201	.238	.936	1.848	1.272
.064	.209	.234	.288	.385	.302	.876	2.028	1.140
.115	.172	.256	.320	.330	.302	1.020	3.194	1.356
.159	.251	.290	.394	.417	.367	1.128	3.648	1.332
.190	.297	.278	.331	.341	.317	1.212	5.064	1.608
.212	.240	.299	.351	.471	.374	1.368	5.412	1.584

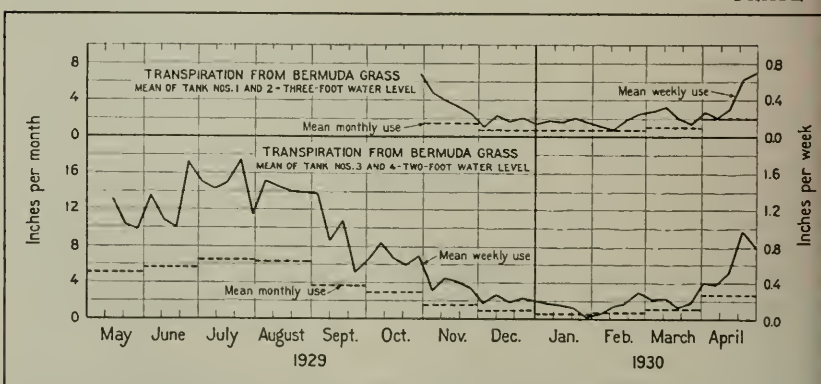
San Bernardino Station.—At the San Bernardino station, located at the Antil plant of the San Bernardino Water Department, four tanks operated in pairs are filled with undisturbed Chino silt loam and all contain the original Bermuda grass cover. The soil tanks are connected to Mariotte supply tanks.

PLATE V



MEAN WEEKLY AND MONTHLY USE OF WATER BY TANKS 1 TO 15, INCLUSIVE, SANTA ANA STATION, 1929–1930.

PLATE VI



MEAN WEEKLY AND MONTHLY USE OF WATER BY TANKS 1 TO 4, INCLUSIVE, SAN BERNARDINO STATION, 1929–1930.

Tank Nos. 1 and 2 at this station maintain a soil water level three feet below the surface and Tank Nos. 3 and 4 have a two-foot water level. Tank No. 2 has given some trouble in operation and so many of the records relating thereto are so unreliable that much of the season's work has been omitted from the final results.

TABLE 6

SUMMARY SHOWING WEEKLY EVAPORATION FROM SOIL AND WATER SURFACES AND USE OF WATER BY SALT GRASS AND TULES, MAY, 1929, TO MAY, 1930, IN TANKS AT SANTA ANA

Measurements in Acre-Inches per Acre

Week ending	Tank number																						
	1	2	3	Mean	4	5	6	Mean	7	8	9	Mean	10	11	12	Mean	13	14	15	Mean	16	19	20
1929—																							
May 7					0.689	0.660	0.274	0.541	0.296	0.862	0.699	0.619	0.105	0.000	0.180	0.095							2.064
May 14					.561	.597	.253	.470	.275	.561	1.003	.613	.074	.000	.277	.117					1.716		2.160
May 21					.445	.523	.232	400	.275	.293	.624	.397	.053	.000	.127	.060					1.488		1.740
May 28					.359	.450	223	.344	.371	.429	.741	.514	.032	.000	.096	.042					1.518		1.554
June 4					.275	449	.210	.311	626	.481	1.111	.739	.053	.022	.097	.057					2.016		2.124
June 11					.296	.449	.136	.294	.964	.398	1 007	.790	.063	.021	.179	.088					1.896		1.776
June 18					.233	.355	.158	.249	.975	.670	.975	.873	.064	.115	.234	.138					1.622		1.694
June 25					222	.323	.115	.220	1.632	1.167	1 461	1.420	.223	.191	.519	.311					1.932		2.256
July 2					232	.251	.180	.221	1.281	1.178	1 154	1.204	.216	.333	482	.344					1 728		1.752
July 9	No evaporation from Tank Nos. 1, 2 and 3 with water table at depth of four feet, May 1 to October 1, 1929.				085	.229	.168	.161	1 217	1.251	1 132	1.200	.314	.265	.366	.315					1 836		1.920
July 16					190	.188	.180	.186	1 282	1.442	1 323	1.349	.414	444	.587	.482					1.872		2.196
July 23					.169	.177	.147	.164	1.325	1.462	1.335	1 374	.764	.462	.636	.621					1.920		2.124
July 30					.180	.167	.169	.172	1.208	1 315	1.176	1.233	.996	.551	823	.790					1 896		1.932
August 6					.169	.293	.136	.199	1.154	1 283	1.334	1.257	.773	.508	.944	.742					1 728	3.827	1.968
August 13					.170	.251	.158	.193	1.048	1.271	1.166	1 162	770	.508	.870	.716	0 254	0.449	0.353	0.352	1 692	4 107	1.812
August 20					.158	.249	.126	.178	1.165	1.314	1.282	1.254	1.049	439	.373	620	.848	.866	1.465	1.060	2.100	5.400	2.160
August 27					.157	.218	.157	.177	1.101	1.314	1 227	1.214	.413	579	.561	.518	.542	.824	1.197	854	1.920	5.850	1.944
September 3					.159	.241	.155	.185	1.144	1.430	1.292	1.289	.690	.593	.689	.657	.392	738	1.336	.822	1.942	7.324	2.026
September 10					.158	.261	.184	.201	.744	.840	.868	.817	.604	.308	625	.512	.488	.514	.749	.584	1.332	4 951	1.188
September 17					.094	.177	.020	.097	816	945	890	.884	.514	.466	.276	.419	552	.450	.685	.562	1.396	6.190	1.408
September 24					.032	.136	.084	.084	.646	.661	605	.637	.343	.273	.270	.295	.318	.524	.546	.463	1.080	4 838	1 116
October 1					.105	.157	.105	.122	.785	.881	.838	.835	403	.138	.515	.352	.531	479	.748	.586	1.344	6.188	1.380
October 8	0.115	0.890	0.413	0 473	.127	166	.073	.122	.890	.998	.933	.940	.540	.445	.737	.574	.572	.372	.696	.547	1 416	7.284	1 620
October 15	.084	.306	.499	.296	.126	.156	.084	.122	.667	.735	.689	.697	.403	.243	.646	.431	.499	.502	.588	.530	1.020	4.894	1.092
October 22	.084	.180	.254	.173	.106	.125	.106	.112	.669	.735	689	.698	.233	.259	.487	.326	.490	.385	.546	.474	1.092	5.738	1.092
October 29	.074	.064	.095	.078	.147	.178	.115	.147	837	.840	.817	.831	.073	.147	.343	.188	.403	.438	.641	.494	1.524	7.651	1.632
November 5	.075	.106	.180	.120	127	.187	.096	.137	.848	.923	.784	.852	414	.297	.123	.278	.511	.417	.600	.509	1.344	7 427	1.500
November 12	.105	.053	.064	.074	.126	.156	.095	.126	.636	.661	.572	.623	.340	.196	.021	.186	.435	.385	.492	.437	1.416	6 526	1.464
November 19	.074	.084	.126	.095	.106	.135	095	.112	647	.713	.593	.651	.243	.173	.000	.139	.403	.309	.491	.401	1.032	4 952	1.236
November 26	.084	.032	.042	.053	.127	.104	.096	.109	521	.565	.478	.521	.240	.177	.000	.139	.371	.310	.395	.359	1.080	4 388	1.008
December 3	.074	.084	.094	.084	.075	.137	.064	.092	413	429	.392	411	.270	.138	.036	.148	.295	.245	.197	.246	.600	2.700	.636
December 10	.064	.031	.074	.056	.053	.074	074	.067	317	.324	.265	.302	.217	.107	.070	.131	.159	.266	.324	.250	.504	2.247	.540
December 17	.063	.043	.085	.064	.053	.063	.042	.053	.285	.313	.307	.302	.166	.138	.022	.109	.128	.246	.175	.183	.492	1.911	492
December 24	.053	000	021	.025	.106	.104	.096	.101	434	471	.434	446	.196	.099	.222	.172	.211	.192	.386	.263	.948	3.261	1 004
December 31	.074	.000	.075	.050	.063	.116	.063	.081	435	460	.392	429	.176	.114	.117	.136	.286	.267	.363	.305	.912	3.037	1 188
1930—																							
January 7	.074	.000	.032	.035	116	.105	.074	.098	297	.345	.329	.324	265	.148	.095	.169	.272	.287	.277	.279	.636	.636	.612
January 14	.074	.000	.042	.039	.074	.074	.073	.074	148	.031	.127	.102	.084	043	.063	.063	.137	.234	.085	.152	.252	.252	.408
January 21	.011	.000	.010	.007	.031	.010	.032	.024	.137	.000	.063	.067	.052	.000	.010	.021	.063	.140	097	.100	.300	.300	.456
January 28	.010	.000	.032	014	.021	.000	.042	.021	.192	.105	148	.148	.106	.000	.011	.039	.137	.288	.160	.195	.336	.336	.480
February 4	.010	.000	010	.007	.032	.043	.032	.036	.243	.250	244	.246	.169	.021	.010	.067	.042	.235	.160	.146	.720	871	852
February 11	.032	.000	.021	.018	.021	.031	.021	.024	.211	.187	.169	.189	.084	.053	.000	.046	.106	.277	.181	.188	.336	.588	.492
February 18	.031	.000	.021	.017	.052	.063	.063	.059	.286	.313	.318	.306	.127	.125	.032	.095	.126	.211	.256	.198	.708	1.152	876
February 25	.021	.000	.021	.014	.074	.042	.063	060	.222	136	.148	.169	.169	.063	.010	.081	.148	.171	.255	.191	.552	.730	552
March 4	.064	.000	.022	029	.021	.021	.042	.028	.201	.188	.211	.200	.168	.127	.021	.105	.169	.265	.203	.212	.708	1.035	.820
March 11	.043	.000	.042	.028	.031	.043	.042	.039	.265	.281	.275	.274	.147	.095	.000	.081	.181	.203	.331	.238	.744	.984	.924
March 18	.021	.000	.021	.014	.064	.074	.032	057	223	.229	.233	.228	.063	.074	.000	.046	.203	.448	.159	.270	.684	.948	840
March 25	.021	.000	.032	.018	.010	.041	.031	.027	.328	.387	.392	.369	.116	.084	.074	.091	.192	.320	.201	.238	.936	1.848	1.272
April 1	.021	.000	.052	.024	.053	.064	.042	.053	435	.491	.520	.482	.361	.201	.064	.209	.234	.288	.385	.302	876	2.028	1.140
April 8	.021	.000	.000	.007	.032	.063	.064	.053	.499	.544	.539	.527	.243	.159	.115	.172	.256	.320	.330	.302	1.020	3.194	1.356
April 15	.000	.000	.053	.018	.063	.115	.021	.066	.540	650	.732	.641	446	.148	.159	.251	.290	.394	.417	.367	1.128	3 648	1.332
April 22	.021	.000	.031	.017	.074	.095	073	.081	.668	.800	.943	.804	.424	.276	.190	.297	.278	.331	.341	.317	1.212	5.064	1.608
April 29	.000	.000	032	.011	084	.178	.063	.108	.678	.756	.921	.785	.297	.212	.212	.240	.299	.351	.471	.374	1.368	5 412	1.584

In Plate VI the mean results for each pair of tanks are plotted. The weekly use of water by Bermuda grass in tanks at San Bernardino is given in Table 7.

TABLE 7

SUMMARY SHOWING WEEKLY USE OF WATER BY BERMUDA GRASS, MAY, 1929, TO MAY, 1930, IN TANKS AT SAN BERNARDINO

Measurements in Acre-inches per Acre

Week ending	Tank numbers			Tank numbers		
	1	2	Mean	3	4	Mean
1929—						
May 14	1.155			1.293	1.325	1.309
May 21	1.006			1.112	.964	1.038
May 28	.828			1.081	.869	.975
June 4	1.198			1.621	1.072	1.347
June 11	.879			1.292	.859	1.075
June 18	.828			1.070	.921	.996
June 25	1.558			1.993	1.451	1.722
July 2	1.389			1.653	1.336	1.495
July 9	1.187	NOTE:—Records for tank No. 2 could not be relied upon before October.		1.537	1.314	1.425
July 16	1.175			1.622	1.356	1.489
July 23	1.497			1.823	1.655	1.739
July 30	1.137			1.315	.964	1.140
August 6	1.490			1.631	1.388	1.510
August 13	1.121			1.601	1.304	1.452
August 20	1.212			1.495	1.281	1.388
August 27	1.098			1.494	1.273	1.383
September 3	1.118			1.548	1.177	1.362
September 10	.688			.837	.869	.853
September 17	.742			1.219	.911	1.065
September 24	.508			.520	.497	.508
October 1	.582			.636	.636	.636
October 8	.656	0.942	0.799	.912	.742	.827
October 15	.901	.403	.652	.667	.645	.656
October 22	.542	.762	.652	.594	.583	.588
October 29	.466	.902	.684	.772	.593	.683
November 5	.406	.540	.473	.317	.286	.301
November 12	.400	.382	.391	.498	.392	.445
November 19	.264	.365	.315	.424	.372	.398
November 26	.232	.261	.246	.327	.349	.338
December 3	.074	.126	.100	.212	.128	.170
December 10	.149	.286	.217	.266	.255	.260
December 17	.200	.127	.164	.212	.137	.175
December 24	.205	.201	.203	.201	.233	.217
December 31	.167	.084	.125	.201	.181	.191
1930—						
January 7	.105	.222	.169	.148	.179	.164
January 14	.139	.188	.163	.190	.116	.153
January 21	.202	.190	.196	.127	.106	.117
January 28	.160	.148	.154	.010	.032	.021
February 4	.044	.180	.112	.064	.042	.053
February 11	.063	.074	.068	.147	.106	.126
February 18	.138	.222	.180	.212	.125	.168
February 25	.265	.232	.249	.276	.297	.287
March 4	.298	.264	.281	.181	.233	.212
March 11	.373	.264	.318	.201	.265	.233
March 18	.285	.106	.196	.074	.191	.132
March 25	.180	.105	.143	.116	.222	.169
April 1	.213	.329	.271	.614	.191	.402
April 8	.211	.201	.206	.561	.223	.392
April 15	.466	.159	.312	.657	.381	.519
April 22	.571	.688	.630	1.039	.901	.970
April 29	.774	.624	.699	.785	.773	.779

The Water-Year.—Ordinarily what is termed the "water-year" begins October 1 of each year and some investigators have adopted this as the time for the division of summer and winter records. In studying the graphs given in this connection it is to be noted that in most cases the plotted line shows a sharp downward break early in September. This is more particularly the case with the grass-covered tanks and the evaporation pans than for the bare surface soil tanks, and it applies alike to tanks operated with the two, three and four-foot water levels. There also is a decline in the mean monthly temperatures, but in a lesser degree. The question as to the particular time when transpiration losses begin to decrease has been raised. In the past year it is evident that in the first week in September there was a decrease in the use of water by grass vegetation amounting to about 40 per cent of the use during the preceding month. The evaporation pans and ground tanks also showed a decrease of about 36 per cent, a greater difference than is found for any other period.

Protecting Soil Tanks From Rainfall.—In studying evaporation from soil tanks having fixed water levels, it is evident that periods of adjustment of soil moisture must take place before evaporation can be accurately measured. The movement of water in the soil occurs by capillary action, a relatively slow process, and in moving from the water table to the soil surface it must first moisten the soil through which it passes. This undoubtedly accounts for the high rate of evaporation recorded in May and June, 1929, for Tank Nos. 1 to 6 and 13 to 15, inclusive. After soil storage is complete all water moved by capillarity may be accounted as evaporation. The moisture thus held in the soil has not a uniform percentage through each foot of depth, but, if the soil is uniform, increases at a fairly regular rate from the surface to the water table as is shown in Table 5. Then with soil storage in equilibrium and normal evaporation taking place if the soil surface is moistened by sufficient rainfall, the storage in the upper soil, which contains the least moisture, may be increased to field capacity and, with a heavy rain, water will penetrate to the water table and be wasted through the overflow waste pipe. When this occurs no evaporation will be registered from the Mariotte tank until the soil storage acquired through rainfall has evaporated and the soil moisture in the tank returned to normal. Over a long period total evaporation may be computed by taking into account depth of rainfall upon the tank surface and amount of water wasted through the overflow pipe, but accurate daily, weekly and, in some cases, monthly records will be impossible.

In order to avoid such complications, all tanks were covered during rains of the past season, a circular sloping metal cover, standing upon metal legs six inches high, being placed over each soil tank during rainy weather. As these covers were elevated above the ground, they allowed free circulation of air over the surfaces of the tanks beneath them and it is thought they did not materially retard evaporation.

Results of Soil Tank Operation.—Records of soil evaporation and consumptive use of water by salt grass and Bermuda grass show varying results, depending upon depth to water table and climatic and seasonal variations. It has been shown that evaporation did not occur from tanks containing Hanford fine sandy loam with bare surfaces when the water table depth was four feet, although the record continued for five consecutive summer months. With the water table in the same tanks raised one foot almost no evaporation is occurring even in warm weather. Table 8 gives a summary of the monthly evaporation from soil and water surfaces and use of water by salt grass and tules at Santa Ana. This summary shows the mean total evaporation from Tank Nos. 1, 2, and 3 for the seven-month period from October, 1929,

TABLE 8

SUMMARY SHOWING MONTHLY EVAPORATION FROM SOIL AND WATER SURFACES AND USE OF WATER BY SALT GRASS AND TULES, MAY, 1929, TO MAY, 1930, IN TANKS AT SANTA ANA

Measurements in Acre-inches Per Acre

Tank No.	May	June	July	August	September	October[1]	November	December	January	February	March	April	Number of months	Total	Per cent of Tank No. 20	Depth to water table feet	Surface of tank
1	....	....	....	....	....	0.399	0.370	0.275	0.179	0.148	0.085	0.084	7	1.540	....	4-3	Bare soil, undisturbed
2	....	....	....	....	....	1.493	.338	.074	0.000	0.000	0.000	0.000	7	1.905	....	4-3	Bare soil, undisturbed
3	....	....	....	....	....	1.399	.443	.265	.126	.074	.137	.137	7	2.581	....	4-3	Bare soil, undisturbed
Mean	....	....	....	....	....	1.097	.384	.205	.102	.074	.074	.074	7	2.010	6.7	4-3	Bare soil, undisturbed
4	2.160	1.099	0.709	0.696	0.474	0.559	0.444	0.339	0.242	0.189	0.148	0.316	12	7.375	....	2	Bare soil, undisturbed
5	2.418	1.555	.908	1.084	.815	.708	.552	.462	.200	.189	.201	.535	12	9.627	....	2	Bare soil, undisturbed
6	1.076	.663	.727	.651	.453	.421	.371	.307	.242	.179	.147	.263	12	5.500	....	2	Bare soil, undisturbed
Mean	1.885	1.106	.781	.810	.581	.563	.456	.369	.228	.186	.165	.371	12	7.501	10.6	2	Bare soil, undisturbed
7	1.440	4.916	5.530	5.019	3.319	3.413	2.662	1.630	0.858	0.984	1.293	2.502	12	33.566	....	2	Salt grass sod
8	2.417	3.296	5.964	5.908	3.737	3.696	2.861	1.736	.554	.896	1.441	2.862	12	35.368	....	2	Salt grass sod
9	3.501	4.978	5.410	5.666	3.571	3.447	2.458	1.557	.752	.867	1.473	3.326	12	37.006	....	2	Salt grass sod
Mean	2.453	4.397	5.635	5.531	3.542	3.519	2.660	1.641	.721	.916	1.402	2.897	12	35.314	50.0	2	Salt grass sod
10	0.275	0.477	2.714	3.451	1.907	1.377	1.326	0.914	0.549	0.612	0.729	1.463	12	15.794	....	4	Salt grass sod
11	....	.592	1.865	2.330	1.408	1.164	.869	.521	.191	.347	.454	.837	12	10.578	....	4	Salt grass sod
12	.702	1.304	2.714	3.097	1.792	2.457	.117	.467	.189	.042	.148	.719	12	13.748	....	4	Salt grass sod
Mean	.326	.791	2.431	2.959	1.702	1.666	.771	.634	.310	.334	.444	1.006	12	13.374	19.0	4	Salt grass sod
13	....	....	....	1.834	2.069	2.221	1.695	0.911	0.651	0.454	0.862	1.219	9	11.916	....	2	Bare soil, disturbed
14	....	....	....	2.792	2.256	1.857	1.431	1.067	1.067	.829	1.418	1.460	9	14.177	....	2	Bare soil, disturbed
15	....	....	....	4.223	3.038	2.770	1.957	1.263	.673	.916	1.118	1.677	9	17.635	....	2	Bare soil, disturbed
Mean	....	....	....	2.950	2.454	2.283	1.694	1.080	.797	.733	1.133	1.452	9	14.576	32.5	2	Bare soil, disturbed
16	[2]5.574	7.910	8.196	8.328	5.762	5.640	4.884	3.060	1.860	2.436	3.384	4.968	11¾	62.002	91.0	....	([3])
19	....	....	....	23.460	23.750	28.380	23.350	11.300	1.860	3.610	6.020	17.590	9	139.320	197.6	....	([4])
20	8.394	8.234	8.892	8.904	5.654	6.060	5.256	3.444	2.280	2.872	4.476	6.048	12	70.514	100.0	....	([5])

[1] Raised water table in Tank Nos. 1, 2 and 3 from four feet to three feet October 1st.
[2] Began May 8, 1929.
[3] Free water in ground tank, diameter 23 1/16 inches.
[4] Tules standing in water, tank diameter 25 9/16 inches.
[5] Weather Bureau pan, diameter four feet.

to May, 1930, to be 2.01 inches, or 6.7 per cent of the amount evaporating from the standard pan.

It has been pointed out when a water table in the soil is raised to a higher level, soil moisture adjustments occur and the record obtained from the Mariotte tank immediately after the change is greater than the actual evaporation. This appears to be the case with these three tanks, as the record shows that the mean amount drawn from the three Mariotte tanks in October was one-half of the amount used in the entire seven months. If only one-third or one-half of the October records, as given, be allowed, the final result will be more nearly correct.

The same general result is noticeable in the records for the second tank set, which includes Tank Nos. 4, 5 and 6. The records for both May and June give larger amounts than those of any of the following months, and absorption by the soil during this period is the only method of accounting for this condition. It appears that, because of soil moisture changes occurring in the soil tank, permanent records should not be taken until a period of six or eight weeks has elapsed after the water table is established. If at any time the water level is changed to a higher or lower level this delay would cause a break in the record. If the water level is lowered, a similar soil moisture change would occur, but it is possible the readjustment period might be shortened somewhat, as the movement of water would be aided by gravity instead of working against it.

In the records of Tank Nos 13, 14 and 15 no increase in use occurred during the first month after the tanks were put in operation, the probable reason being that two or three weeks prior to taking the first records the soil was saturated throughout. Attention has been called to these tanks as check tanks to determine the difference in evaporation between disturbed and undisturbed soil. It was expected that in the rearrangement of the disturbed soil, the soil mass would be looser and the capillary spaces larger, with resulting greater evaporation. Reference to Table 8 indicates that this was the case. The tabulated results show that the total mean evaporation from Tank Nos. 13, 14 and 15, containing disturbed soil, was 14.576 inches during the nine-month period from August, 1929, to April, 1930, inclusive, and that there was a mean evaporation of only 3.729 inches from Tank Nos. 4, 5 and 6 during the same period.

Table 9 sums up the monthly evaporation from water surfaces and the consumptive use of water by Bermuda grass in tanks at San Bernardino.

The Mariotte Tank.

Measuring the evaporation of water from bare soil surfaces or its consumptive use by vegetative growth in soil tanks is greatly simplified by the use of the Mariotte tank, as previously developed and used by members of the Division of Agricultural Engineering.* Previous to this development the study of soil moisture through the use of tanks necessitated weighing the tanks with their contents at intervals to determine the amount of water lost. This method involved a number of

* Experiments to determine rate of evaporation from saturated soils and river-bed sands, by Ralph L. Parshall, Senior Irrigation Engineer, U S. Department of Agriculture; Proceedings, American Society of Civil Engineers, April, 1929.

TABLE 9

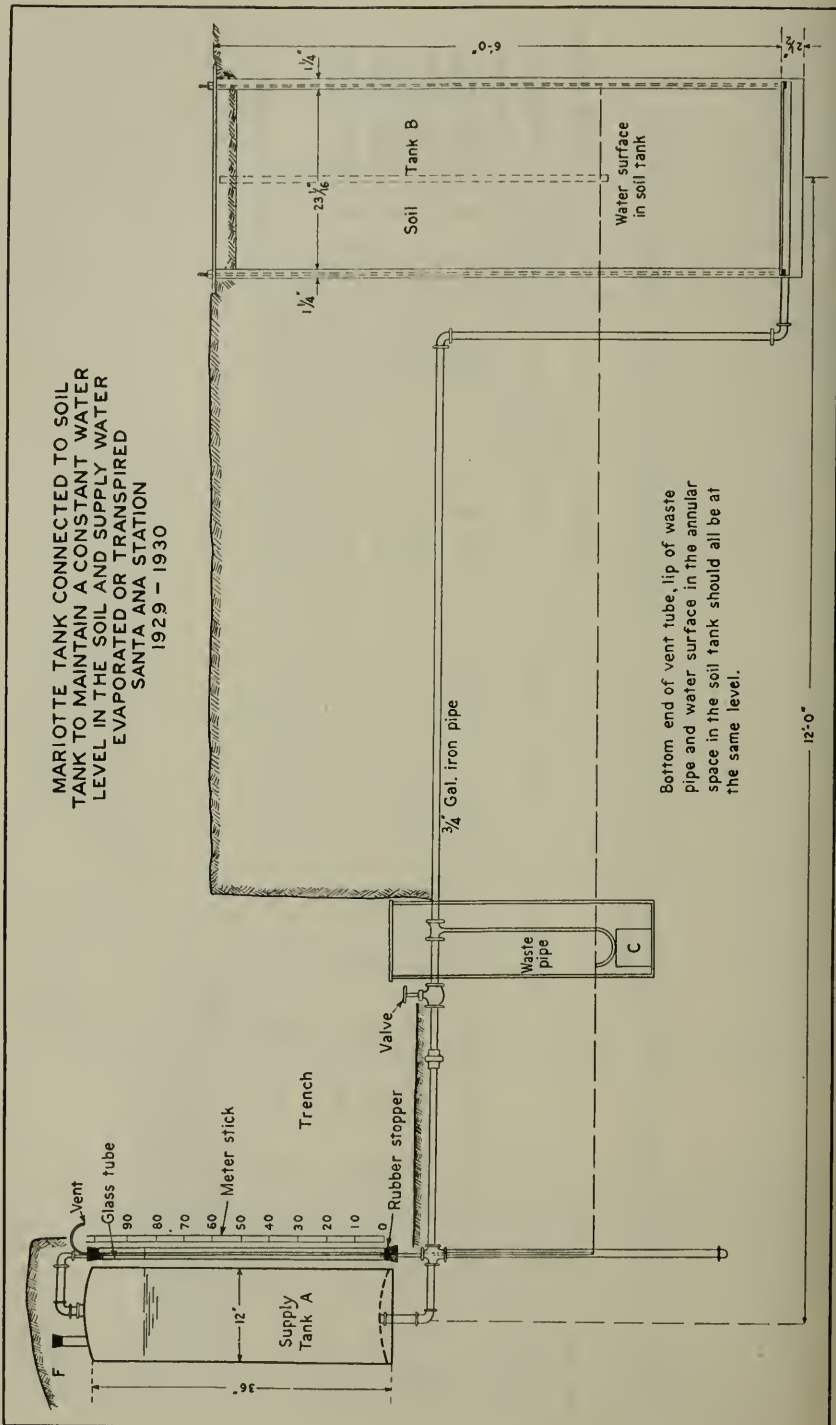
SUMMARY SHOWING MONTHLY EVAPORATION FROM WATER SURFACES AND USE OF WATER BY BERMUDA GRASS AND TULES, MAY, 1929, TO MAY, 1930, IN TANKS AT SAN BERNARDINO

Measurements in Acre-inches Per Acre

Tank No.	[1]May	June	July	August	September	October	November	December	January	February	March	April	Number of months	Total	Per cent of Tank No. 7	Depth to water table feet	Surface of tank
1	4.280	5.216	5.489	5.345	2.901	2.771	1.255	0.719	0.650	0.647	1.136	2.139	12	32.548	--------	3	Bermuda grass sod
2	--------	--------	--------	--------	--------	--------	1.505	.761	.886	.676	.877	1.798	6	6.503	--------	3	Bermuda grass sod
Mean	4.280	5.216	5.489	5.345	2.901	2.771	1.380	.740	.768	.662	1.006	1.968	--------	32.526	45.5	3	Bermuda grass sod
3	5.340	6.348	7.144	6.804	3.785	3.061	1.641	1.007	0.475	0.742	1.122	3.063	12	40.532	--------	2	Bermuda grass sod
4	4.840	4.854	5.872	5.660	3.337	2.722	1.410	.849	.433	.676	.975	2.373	12	34.001	--------	2	Bermuda grass sod
Mean	5.090	5.601	6.508	6.232	3.561	2.892	1.525	.928	.454	.709	1.048	2.718	12	37.266	52.1	2	Bermuda grass sod
5	6.090	7.596	8.892	7.740	5.426	5.436	4.704	3.480	2.220	2.676	3.912	5.400	12	63.572	88.9	--------	(4)
6	--------	--------	--------	8.296	[2]5.562	--------	--------	--------	--------	--------	--------	[3]11.120	--------	--------	--------	--------	(5)
7	7.780	8.892	9.780	8.808	5.690	5.580	4.980	3.816	2.316	3.456	5.016	5.376	12	71.490	100.0	--------	(6)

[1] Records began May 6, 1929, but totals are proportioned for full month.
[2] Bermuda grass growing in water in August and September, diameter of tank 23 1/16 inches.
[3] Tules growing in water, diameter of tank 23 1/16 inches.
[4] Free water in ground tank, diameter 23 1/16 inches.
[5] Standing in water, tank diameter 23 1/16 inches.
[6] Weather Bureau pan, diameter four feet.

PLATE VII



MARIOTTE TANK CONNECTED TO SOIL TANK TO MAINTAIN A CONSTANT WATER LEVEL IN THE SOIL AND SUPPLY WATER EVAPORATED OR TRANSPIRED
SANTA ANA STATION
1929 – 1930

processes eliminated by the use of the Mariotte automatic supply system, which furnishes water as needed to maintain a fixed water level in the annular space in the soil tank. The tank equipment is shown in Plate VII.

This device consists essentially of a supply tank equipped for Mariotte regulation and connected to the soil tank by means of a three-fourths inch pipe. A twelve inch by 36-inch galvanized iron range boiler, chosen because of its solid construction, rigidity of its connections, and the practicability of keeping it airtight, was found to be satisfactory for the purpose. Mounted upon the side of the supply tank is a vertical length of one and one-fourth inch glass tubing. Each end of the glass tube is fitted with a rubber stopper perforated to allow a fourth inch pipe to project into the tube. The lower pipe connects with the three-fourth inch supply pipe to the soil tank, while the upper passes into the upper part of the supply tank, making a water glass which indicates the height of water in the reservoir tank. The lower one-fourth inch pipe should not project above the rubber stopper, otherwise the glass tube could not be entirely drained to prevent freezing. Upon the glass gage is mounted a meter stick or scale upon which differences in daily readings determine the amount of water withdrawn. In the supply pipe between the reservoir and the soil tank is a valve by which the supply reservoir and the tank may be disconnected while the former is being refilled. There also is a brass waste pipe which discharges any excess water in the soil tank into the container C. The lip of the waste pipe is set at the level of the water in the soil tank. In the drawing it is shown below the connecting supply pipe, but with a higher water table it might be above the supply pipe. In all cases the overflow and the container are protected by a covering.

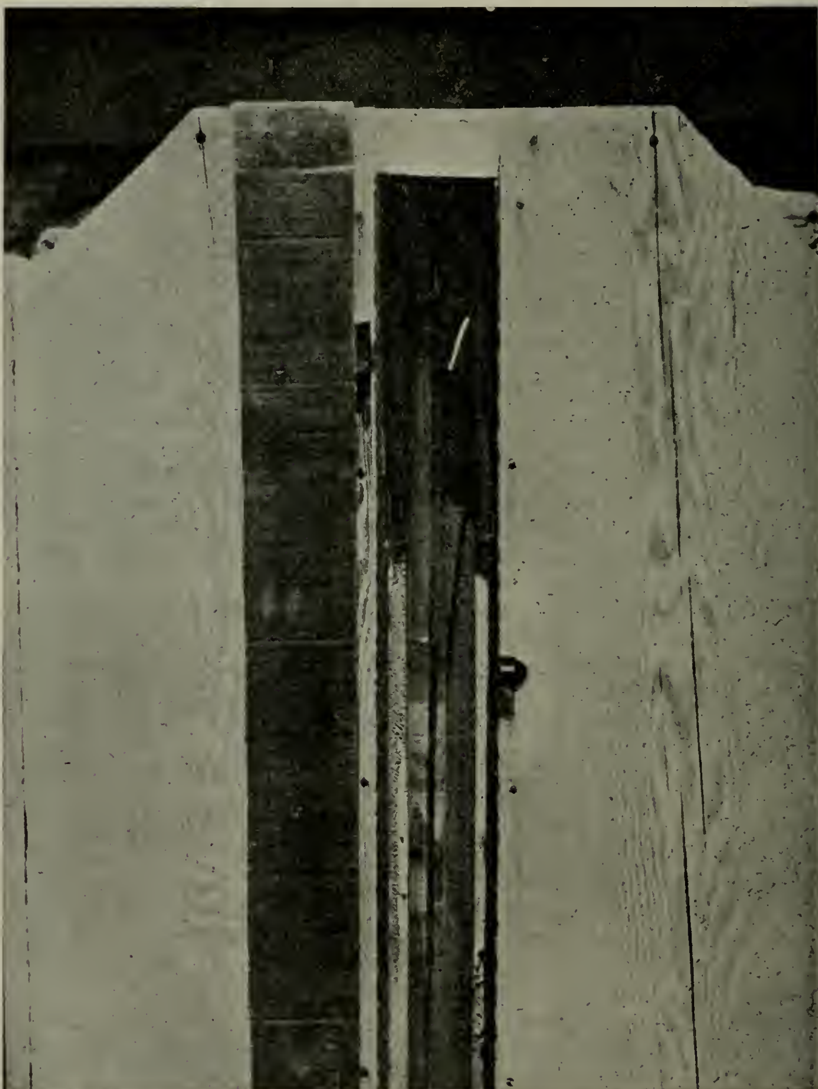
The filling point of the reservoir tank F consists of a short section of pipe screwed into the top of the reservoir. It is closed by a rubber stopper, which makes a complete seal and prevents air from being drawn into the partial vacuum chamber below. The vent tube is a three-sixteenth inch copper tube passing through the rubber stopper at the top of the glass gage. This tube is open at both ends and the level of the soil water is determined by the elevation of the bottom end of the vent. In Plate VII the water table in the soil tank is at such a depth that it was necessary to extend the vent tube downward into an extension well below the supply pipe, this well being made deep enough to allow for future lowering of the soil water if so desired.

It has previously been determined* that variations of temperature cause expansion and contraction of the air in the supply tank above the water surface and that inaccuracies in the water level result from corresponding changes of vapor pressure. To insulate the Mariotte tanks as much as possible, those at Santa Ana were set two feet in the ground and the exposed portions covered with earth. The front of each tank is faced with boards, as indicated in Plate VIII, a narrow hinged door, four inches wide, giving access to the full length of the glass gage and meter stick. Except for this narrow doorway the entire tank is surrounded and covered with earth. Because of the general high ground water plane prevailing at the San Bernardino station,

* Experiments to determine the rate of evaporation from saturated soils and river-bed sands, discussion by Carl Rohwer, Associate Irrigation Engineer, U S. Department of Agriculture; Proceedings, American Society of Civil Engineers, January, 1930.

the four Mariotte tanks in use at that place are set above ground and enclosed in white painted boxes, each of which has both a narrow doorway opening upon the glass gage and a hinged top to allow for refilling. The box is filled with shavings and the tank wrapped with

PLATE VIII



BOARD FRONT FOR MARIOTTE TANK SHOWING DOORWAY WITH GLASS TUBE AND METER STICK INSIDE, SANTA ANA STATION, 1929.

asbestos paper. At Santa Ana, for convenience in taking readings, a narrow trench passes along the front of all Mariotte tanks to give easier access to the observation doors. To prevent any sudden change of temperature within the supply tank, due to penetration of rainfall upon the adjacent soil, all supply tanks are covered with a corrugated metal roof, beneath which there is a free circulation of air.

*Operation.**—At the beginning of a series of observations with a Mariotte tank (A) and a soil tank (B), as illustrated in Plate VII, it is assumed that water is standing in the annular space in the soil tank at some level below the bottom of the vent tube. With the valve in the supply line closed, tank A is filled and the filling tube at F closed by the rubber stopper. At this time the water, both in tank A and the vent tube, is at the same level and the pressure in each is atmospheric, the same as on the water surface in the soil tank. If, now, the valve between the tanks is opened, water flows from A to B, rises in B, lowers in A and, because tank A is an air-tight container, a partial vacuum forms in the chamber above the water surface. Water also falls in the vent tube, but at a greater rate than in tank A.

If h_a = the pressure head corresponding to atmospheric pressure

h_v = the pressure head corresponding to the partial vacuum in the space above the water surface in A,

and h_w = the pressure head corresponding to the column of water equal to the difference in elevation between the water surface in A and the bottom of the vent tube,

then, ignoring capillarity, the water in the vent tube will be lower than in A by an amount equal to $h_a - h_v$ and this difference will increase until

$$h_a - h_v = h_w \qquad (1)$$

at which time the water in the vent tube will stand at the bottom of the tube. To start a flow of air through the vent tube the atmospheric pressure head (h_a) must be slightly greater than the sum of the opposing pressure heads due to the column of water and the partial vacuum in the tank, or

$$h_a \text{ is greater than } h_w + h_v \qquad (2)$$

When this condition occurs air will pass downward through the vent tube and bubbles will rise through the glass tube and pass into the partial vacuum chamber above the water surface in tank A. Bubbling will continue as long as water flows from A to B, or until the horizontal plane through A, upon which the pressure head is atmospheric (the condition existing at the bottom of the vent tube), is equal in elevation to the horizontal plane of the water surface in B, upon which the pressure head also is atmospheric. As the pressure head is the same in each tank at the same level there is no head to cause further flow and the bubbling will cease until the water surface falls in B or something occurs to change the value of h_v.

This value is easily affected by any leakage of air through any one of the many pipe connections between the two tanks or around the rubber stoppers or other connections with the glass tubes. In install-

* Authors are indebted to Major O. V. P. Stout of the Division of Agricultural Engineering who assisted and cooperated in regard to the theory of the Mariotte tank.

ing each tank extreme care was taken to make all connections as tight as possible, and but little trouble has been experienced from this source.

As any minute quantity of air entering the connecting pipe or tank A passes at once into the chamber over the water surface, the value of h_v is immediately increased and that of $h_a - h_v$ is decreased so that in the equation of equilibrium (1) the left hand member of the equation has become less than that on the right and a flow is started from A to B, which will continue until the equation is again balanced. This will tend to raise the water surface in B, but if the lip of the waste pipe is set at the proper level any excess will overflow into the container C where it can be measured and accounted for.

A central well, consisting of a section of three-fourths-inch pipe, was set in the center of each soil tank to provide for measuring the depth to water in the soil. The pipe extends about one inch above the surface and about two inches below the water table. The control of the water level by the Mariotte tank has been very satisfactory in soil Tank Nos. 1 to 12, inclusive, at Santa Ana, although for various reasons there has been some difficulty with other soil tanks. In general, the range of fluctuation is not more than one-half inch either above or below the depth at which it is desired to hold the water and this fluctuation is too small to affect evaporation losses.

Effects of Temperature.—It has been shown that the equation of equilibrium (1) is changed by the admission of air into the partial vacuum chamber of the Mariotte tank, but this is not the only condition that will upset the equation. Temperature changes have a like effect, causing expansion and contraction of the rarified air in the chamber and also a change in the vapor pressure. The combined effect is generally sufficient during a warm day to cause a variation upon the gage stick of several millimeters. When the temperature increases in the Mariotte tank the value of h_v also is increased and water is forced out of the supply tank into the soil tank. Likewise a decrease in temperature will cause a flow in the opposite direction. Although theoretically no such reverse flow is possible, it has been demonstrated that it does occur because of the presence of a small air bubble which forms a seal at the lower end of the vent tube. It is evident, therefore, that Mariotte tanks should be insulated from such temperature changes as completely as possible.

Records at the stations are taken regularly each morning at 8 o'clock, probably before the rising temperature has had time to change the value of the partial vacuum in the Mariotte tanks. The difference of these readings from day to day should represent a true value of the evaporation or transpiration during that period.

When records are taken more frequently than once a day the effect of temperature in changing the water level in the supply tank may give unreliable results and therefore single readings, made early each day, are preferable. Table 10 gives gage readings of Tank No. 4 at San Bernardino from November 29 to December 4, 1929, both at 8 a.m. and at 1 p.m. It also gives the temperature at the time of the morning reading and the maximum temperature of the day, which probably occurred about 1 or 2 o'clock in the afternoon, the minimum temperature during the following night and the condition of the sky. In every instance the

1 p.m. readings were not only lower than the 8 a.m. readings for the same day, but they were lower than the 8 a.m. readings for the following day, showing that the midday increase in temperature caused a lowering of the water in the supply tank at 1 p.m. to a level below that found at 8 a.m. the next day, and also that the decrease in temperature during the night caused a return flow to the supply tank.

TABLE 10

DIFFERENCE IN GAGE HEIGHTS DUE TO TEMPERATURE, MARIOTTE TANK No. 4, AT SAN BERNARDINO STATION

Date	Gage height in centimeters		Difference in millimeters	Temperature in degrees Fahrenheit			Temperature increase between 8 a.m. and 1 p.m. in degrees Fahrenheit	Sky
	8 a.m.	1 p.m.		8 a.m.	1 p.m.	Minimum		
1929—								
November 29	74.8	73.4	14	50	80	33	30	Clear
November 30	74.8	73.8	10	45	76	38	31	Clear
December 1	74.5	74.1	4	48	60	29	12	Cloudy
December 2	74.5	73.4	11	39	73	33	34	Clear
December 3	74.4	73.3	11	46	82	35	36	Clear
December 4	74.1	73.1	10	43	83	40	40	Clear
Total			60				183	
Mean			10				30	

It will be seen that for the period indicated a mean temperature rise of three degrees Fahrenheit between 8 a.m. and 1 p.m. was sufficient to cause the water surface in the Mariotte tank to fall one millimeter. The difference for each 24 hours closely corresponds to the mean for the period. The change of four millimeters on December 1, when the weather was cloudy and the range of temperature was only twelve degrees, was at almost the same rate as for the rest of the period when the temperature change was three or four times as large.

Due to the fact that supply tanks at Santa Ana are completely buried and therefore better insulated against temperature changes than those at San Bernardino, daily fluctuations of the water surface in these tanks are much less than those shown in Table 10.

Consumptive Use of Water by Tules.

The experiments thus far described have been made with reference to evaporation from soil and water surfaces and consumptive use of water by grasses grown in tanks, with the water tables at various fixed depths, under conditions more or less generally applicable to cultivated areas of the locality under consideration. There are, however, areas of a very different class lying along the shores of lakes and rivers and around swamps and springs, where the water is near and possibly above the ground surface and the vegetative growth consists almost entirely of water-loving plants such as the willow, cottonwood, tule, cat-tail, rush, watercress and plants of like nature. That vegetation of this class does not thrive except where there is an abundance of water has long been recognized.

In the Santa Ana Valley moist areas are chiefly restricted to tracts along the river and some of its tributaries. Willows and cottonwoods are abundant along portions of the river and tules increase rapidly each year unless destroyed by floods. While the aggregate area covered by such growths is small compared with the total, the amount of water

PLATE IX

TANK NO. 19, SHOWING DENSITY OF TULE GROWTH AMOUNTING TO 364 STEMS IN 3.5 SQUARE FEET, SANTA ANA STATION, 1930.

which escapes into the air through evaporation and transpiration, while not known, is probably relatively large. It was with the hope of contributing to the knowledge of the use of water by the ordinary round-stemmed swamp tule (Scirpus acutus) that an experiment was begun in July, 1929, to determine the amount of water that it would use under known conditions. Tank No. 19, 25½ inches in diameter and 30 inches deep, was buried with its rim close to the ground surface and planted with tules about eighteen inches high. During the period covered by the investigation the ground surface has been kept submerged under about two inches of water. The plants increased rapidly in number to about 150 shoots in September, the average length of the tule stalks being then about three feet. The tules began to die in November, and throughout January all were dead. In February new growth started and a count in May showed 364 stalks in a tank having a soil surface area of only three and one-half square feet. The tank is shown in Plate IX.

The keeping of records of consumptive use was begun in August, 1929, and they are given for the period to May, 1930, in Table 8. Since compiling this table additional records have been kept and in Table 11 monthly totals of the use of water by tules in Tank No. 19, for the twelve-month period from August 1, 1929, to July 31, 1930, are given.

TABLE 11

MONTHLY USE OF WATER BY TULES GROWING IN SUBMERGED SOIL IN TANK No. 19 AT SANTA ANA STATION[1]

Year	Month	Use of water in inches
1929	August	23.46
	September	23.75
	October	28.38
	November	23.35
	December	11.30
1930	January	[2]1.86
	February	3.61
	March	6.02
	April	17.59
	May	22.57
	June	23.07
	July	28.60

[1] Total evaporation and transpiration loss, 213.56 inches=17.80 feet

[2] Evaporation only taken from Tank No. 16. No records were kept of Tank No. 19 during January, 1930, as all tule tops were dead.

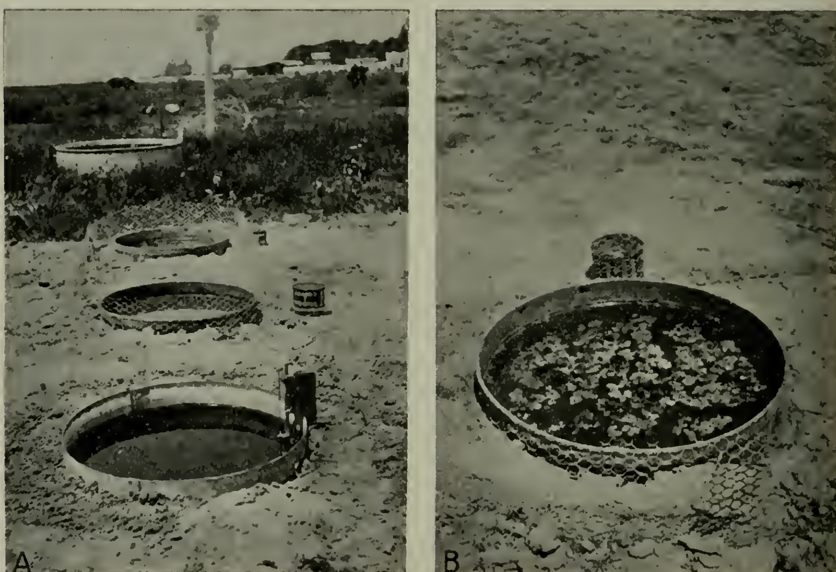
The remarkable total of 213.56 inches for the twelve-month period indicates the desirability of eradicating this kind of growth in order that the water supply of southern California shall not be wasted. The amount given, however, is based upon a single tank experiment and may not closely represent the actual use of water by tules grown under swamp conditions and should, therefore, be used with caution. Furthermore, the effects of insolation, humidity, wind movement and rim effect in a tank test may produce quite different results from those that prevail in a large swamp where humidity is greater, swamp growth is heavier and sun and wind penetrate to the water surface less readily. It is intended that in the near future an experiment for determining the use of water by tules under actual swamp conditions, for comparison with results already obtained, shall be undertaken.

The results of the one tule tank test reported herein have led to a desire for information as to the amount of water used by other varieties of moist area growths, and early in 1930 additional studies, using several kinds of tules and one clump of willow, were undertaken, but no records are available at this time.

Effect of Oil Films on Evaporation.

To insure maximum use of limited water supplies throughout the west, hundreds of reservoirs conserve the flood flows of streams for domestic and agricultural uses and for the development of hydroelectric power. Sometimes the stored water has a very high value. Where irrigation and power are combined under the same system, or when the stream flow is passed through several power houses on the same stream, or in the more arid regions where the water supply is insufficient to satisfy the requirement of irrigation for the arable lands, water may be valued at from $5 to $35 per acre-foot delivered in a single season to the consumer. With such values, any feasible, economical and harmless method of decreasing or preventing evaporation losses from reservoir surfaces will be of great economic value.

PLATE X



TANKS USED IN STUDY OF PREVENTION OF EVAPORATION BY OIL FILMS, SANTA ANA STATION.

A. Three Tanks Used in Study, 1929. Netting Is to Keep Out Frogs.
B. Oil Film Tank Showing Accumulation of Waxy Flakes on Tank Surface, 1930.

With a view to making a study to this end, Tank Nos 17 and 18, shown in Plate X A were used at Santa Ana to determine the benefits of oil films in preventing evaporation from water surfaces in tanks. These tanks, each $23\frac{1}{16}$ inches in diameter by 30 inches deep, were set in the ground with two inches of the rims extending above the ground surface and filled with water to about the same levels. Cylinder oil was used at the arbitrary rate of 100 gallons per acre and each day's evaporation loss was replaced the following morning with a measured amount of water which brought the oil-covered water surface up to a predetermined level. For comparison with evaporation from a free water surface, Tank No. 16 of the same size and exposure was used as a check tank. In this the evaporation was measured with a hook gage. A different oil was used in each of the oil film tanks and each test was continued until the effect of the oil had entirely disappeared. During the continuance of the tests numerous difficulties were encountered and in some cases tests were abandoned after a few days observation and new tests started, as it was found that wind, rain, dust and small animals getting into the tanks were causes of inaccuracies. Altogether a number of tests were begun and abandoned but four tests have been completed. Table 12 gives some of the data. In the first tests the percentages vary considerably and during parts of September oil-covered Tank No. 17 had a greater evaporation loss than was recorded from the free water surface. As the daily loss from Tank No. 16 was measured with a hook gage and that from the other two tanks was measured volumetrically it is probable some error, due to the different methods of measurement, was responsible for this high percentage. In the tests covering April and May, 1930, an outside stilling well was installed in connection with each of the oil-covered tanks to permit hook gage readings to be taken without disturbing the oil surfaces, measurements in all three tanks being made in the same way with the same gage.

The results of the tests have not been satisfactory. When heavy oil is first applied to the water surface it does not spread readily, but collects in pools which gradually extend to cover the tank surface after a period of about 48 hours. Lighter oils spread more readily. It was found that during the early part of the tests the efficiency of the oil in decreasing evaporation was greater than during the latter part, except in Test No. 3 in November and December when the percentage of effectiveness increased. Table 12 shows the saving from evaporation in Test Nos. 1, 2 and 4 to vary from 10.4 to 25.5 per cent, while the saving in Test No. 3 was 48.7 per cent from Tank No. 17 and 53.9 per cent for Tank No. 18, which does not agree with uncompleted Test No. 2 at an earlier date in which the same grade of oil was used. During the period of Test No. 3 the mean air temperature was slightly lower than at other times and the wind movement was less. The test had to be discontinued before it was completed because of trash blowing into the tanks during a high wind. If the experiment had been continued without interruption, final results might have been different.

The decrease in effectiveness during the various tests was due to the evaporation of the lighter portions of the oils or its absorption by the water, which left only the heavier grease or waxy flakes of the oil residue. With time much of the grease seemed to disappear, the water surface remaining partly covered by rather dry, waxy flakes of almost paper thinness, such as are shown in Plate X B, which had little effect in preventing evaporation. In the case of Test No. 3 it is probable that, with the lower air temperatures, less oil was evaporated and the effect of the oil lasted longer, indicating that prevention of evaporation by use of oil films is more effective at the lower temperatures.

It is evident from the results of these experiments that cylinder oils applied at the rate of 100 gallons per acre of water surface are not sufficiently effective in preventing evaporation from water surfaces to warrant their use. When first applied the ratio of evaporation from oil-covered tanks to that from free water varied from 36 to 93 per cent, averaging 71 per cent at the end of the first week of the test. At the end of 30 days the benefit due to the oil had disappeared almost entirely. If it is necessary to replace the oil film approximately every three weeks during the summer period, when the evaporation is greatest, with a saving of but 15 to 40 per cent of the evaporation from a free water surface, the cost of the prevention may equal, or possibly exceed, the value of the water saved. Unless a less volatile oil is discovered which may be applied at very low cost, its use as a preventative cannot be considered a success.

TABLE 12

EVAPORATION FROM OIL-COVERED WATER SURFACES, AS COMPARED WITH FREE WATER SURFACES

Week ending	Mean		Weekly evaporation				
	Air temperature in degrees Fahrenheit	Ground wind, in miles per 24 hrs.	Free water in tank No. 16 in inches	Oil film on tank No. 17 in inches	Water saved by oil film tank No. 17 in inches	Oil film on tank No. 18 in inches	Water saved by oil film tank No. 18 in inches
1929— Test No. 1							
August 20	74		2.100	0.759	1.341	1.373	0.727
August 27	71	48	1.920	1.104	.816	1.474	.446
September 3	77	53	1.942	1.808	.134	1.519	.423
September 10	67	56	1.332	1.381	+.049	.891	.441
September 17	70	50	1.396	1.514	+.118	1.300	.096
September 24	70	42	1.080	.898	.182	.755	.325
September 30	62	39	1.140	1.104	.036	1.167	+.027
Saving by oil					2.342=21.5 per cent		2.431=22.3 per cent
Test No. 2							
October 22	66	37	0.984	0.803	0.181	0.796	0.188
October 29	63	60	1.524	1.197	.327	.927	.597
November 5	61	46	1.344	1.080	.264	1.072	.272
November 10	59	34	.600	.555	.045	.521	.079
Saving by oil					.817=18.4 per cent		1.136=25.5 per cent
Test No. 3							
November 26	56	41	1.080	0.728	0.352	0.636	0.444
December 3	57	28	.600	.350	.250	.261	.339
December 10	56	29	.504	.161	.343	.175	.329
December 17	57	30	.492	.134	.358	.161	.331
Saving by oil					1.303=48.7 per cent		1.443=53.9 per cent
1930— Test No. 4							
April 15	59	43	1.008	0.888	0.120	0.936	0.072
April 22	62	43	1.212	1.056	.156	.988	.224
April 29	60	47	1.368	1.080	.288	1.056	.312
May 6	57	50	.804	.540	.264	.576	.228
May 13	55	37	1.416	1.416	.000	1.392	.024
May 20	60	35	1.344	1.344	.000	1.344	.000
May 24	63	40	.960	.948	.012	.948	.012
Saving by oil					.840=10.4 per cent		.872=10.8 per cent

Oil Samples Tested

Test No.	Tank No. 16	Tank No. 17	Tank No. 18
1	Free water	Standard Oil product No. 16750R	Standard Oil product No. 16751R
2	Free water	Standard Oil Zerolene F	Standard Oil Zerolene No. 3
3	Free water	Standard Oil Zerolene F	Standard Oil Zerolene No. 3
4	Free water	Standard Oil product B. H. 17541R	Standard Oil product B. H. 17540R

CHAPTER III

PERCHED WATER TABLE IN ORANGE COUNTY

General Discussion.

The Coastal Plain of Orange County is of alluvial origin, consisting of materials deposited by Santa Ana River. The records of many wells of this area show that the plain is composed of deposits of sand, gravel and silt or clay. The coarser materials form the underground basin, from which approximately 80 per cent of all the water used in the county for irrigation and domestic use is pumped, and the surface overlying this underground basin comprises the greater part of the agricultural area. The depth of the deposits is not definitely known, but well logs recorded in the southern portion show unconsolidated material at depths of 1000 feet and more.

Underlying much of the agricultural area, tight silt or clay deposits, forming the impervious cap of an artesian basin more important formerly than now, occur at various depths. This practically water tight cap separates the waters of the underground basin from those on the surface and accounts for the perched water table found at various shallow depths throughout the area lying south and west of a line connecting the towns of Tustin, Santa Ana, Garden Grove, Stanton and Buena Park. North and east of this line the upward slope of the ground surface increases more rapidly and the perched water is found at greater depths. It is thought that at some point in this direction the clay cap disappears and the perched water table and the waters of the underground basin merge in one body at some lower level. It is known that the bed of Santa Ana River will absorb stream flow for several miles above the Chapman Street bridge, west of Orange, and that flood flows passing this point are not absorbed, but continue on to the ocean.

Formerly large areas suffered from a high water table, supplied in part by artesian flow, and lands were of little value for cultivation, salt grass being the principal growth. As farming expanded and land values increased, numerous successful attempts were made to lower the surface water by drainage into the ocean, the surface water being held at depths which allowed sufficient root development for agricultural cropping.

The result of the annual depletion of the underground reservoirs also is apparent in the drainage situation. Artesian wells ceased to flow and pumping at increased cost has become necessary, with the result that less water is used for irrigation and waste is cut to a minimum. Consequently drainage ditches do not carry as much water as they formerly did. Systems which flowed throughout the year now carry water only during the months immediately following the winter rains. Certain areas, however, notably the low peat area near Wintersburg, have a continuous high water table, within two feet of the ground surface. In the northwestern part of the county, also, salt grass, which is an indicator of ground water, is found more extensively than elsewhere.

At the present time the perched water table apparently fluctuates through a yearly cycle, reaching a peak height in the spring after the rainy season and a minimum stage before the rains begin in the late fall. The ground supply is replenished by both rainfall and irrigation by pumping from the deeper levels, and is depleted by soil evaporation, transpiration from crops and other vegetation and by artificial drainage. No use is now being made of the surface water, except from a few shallow wells constructed for domestic purposes. Irrigation pumping is entirely from the deeper underground basin.

Long records of depths to water levels in used wells have shown that the present water table is much lower than the perched water level in the surrounding soil. With a serious shortage of water possible within the next decade, if additional supplies are not procured, it may be desirable to conserve some of the surface water now wasted by evaporation, transpiration and drainage. For example, surface water collected by drainage systems could be diverted to adjacent deep wells or shafts and allowed to pass into the underground basin to replenish the failing supply. With electric power everywhere available, surface water could be pumped directly from shallow pits into existing drainage ditches through which it could flow to the connecting wells. Thus surface waters might be stored below the possibility of further waste and made available for beneficial use, provided that the cost is reasonable.

Surface Test Wells.

In 1927 a representative of the California State Engineer began a study of the surface ground water conditions in western Orange County and established a number of test wells with a view to measuring the fluctuations of the perched water table. In general, these wells were located a mile or two apart, along east and west highways, and covered the greater part of the agricultural portion of the county. For a time in 1928 records were kept by the Orange County Flood Control District and during 1929 by the Division of Agricultural Engineering of the United States Department of Agriculture, which in turn relinquished the taking of the records to the flood control district when its studies were resumed in 1930.

The wells consisted of four-inch uncased holes bored from four to twelve feet deep. In sandy loam soils such wells would not stay open and it was necessary to rebore them for each reading. For various reasons, accurate and continuous records have been impossible in some places, but in general the results have given a very good picture of the fluctuations of the perched water table and show the depths at which this water may be found in different localities at various seasons. This report includes only that part of the investigation during which records were kept by the Division of Agricultural Engineering, but the results obtained are representative of other years as well.

During 1929 no rainfall of importance occurred after April, and in December the surface water stood at the lowest point of the year. During January, 1930, the rainfall amounted to 5.55 inches, in February to 0.55 inch and in March to 2.99 inches. In most cases rains amounted to less than one-half inch per 24 hours, but in January there was one rain of 1.57 inches and in March one of 1.72 inches. Neither one caused surface run-off and consequently all water which fell passed into the soil and a portion of it reached the perched water table. Practically no irrigation occurred during the four-month period from December, 1929, to April, 1930, and the ground water replenishment was due entirely to rainfall penetration. The mean rise along any particular highway for the period indicated is given in Table 13.

TABLE 13

MEAN RISE OF PERCHED WATER TABLE IN ORANGE COUNTY DUE TO RAINFALL BETWEEN DECEMBER, 1929, AND APRIL, 1930

Name of highway	Number of wells measured	Rise of perched water table in feet
Orangethorpe avenue	3	0.7
Lincoln avenue	3	1.1
Cerritos avenue	4	0.9
Ocean avenue	6	1.5
Bolsa avenue	6	1.5
Wintersburg avenue and Delhi road	10	2.0
Garfield avenue	4	2.2
Total number of wells and mean rise	36	1.4

The locations of highways and test wells and contour lines representing depths below the ground surface at which the perched water table was found to lie in April are shown in Plate XI. In most cases the water contours parallel the general direction of the surface contours, but there are some exceptions due to soil conditions.

Rainfall Penetration.

In recent years a lowering of the perched water table underlying the 3500 acres comprising the Newhope Drainage District has been accomplished by the installation of several miles of drain pipe emptying into Santa Ana River. This district lies adjacent to the west bank of the river, in a narrow strip one or two miles in width extending about four miles southerly from the vicinity of Garden Grove as shown in Plate XI. Drains were laid at an average depth of from seven to eight feet and are roughly spaced about one-fourth mile apart. Test wells show that the perched water table now stands at from five to eighth feet below the ground surface throughout the district. The tract, an alluvial deposit of Hanford fine sandy loam and Hanford sand, supports a thriving agricultural community.

Late in 1929, a weir with water register was installed in Manhole 26 of the district drains, located on Smeltzer avenue, for the purpose of measuring the penetration of rainfall in this part of the district. It was estimated as nearly as possible from district maps that the drainage from 1900 acres could be measured at this point. As there has been no rain for several months and the volume of irrigation decreased throughout the latter months of the year, the drainage flow likewise decreased until it was at a minimum prior to the first rains of the season early in January, 1930. That a better idea of the flow measure-

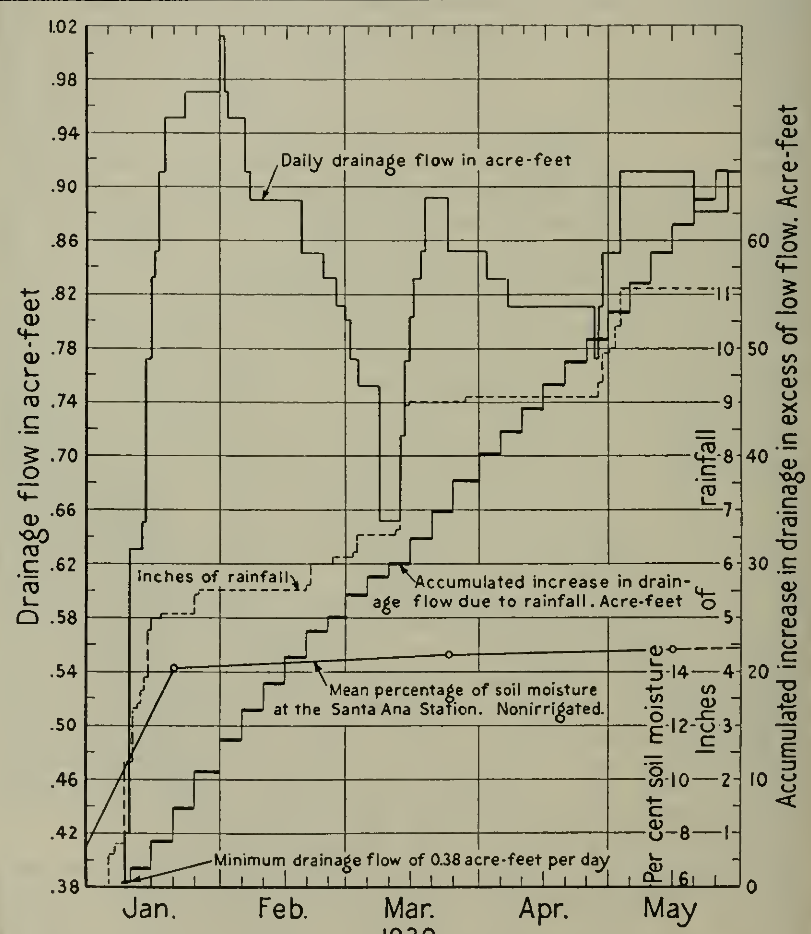
PLATE XI


WESTERN ORANGE COUNTY
SHOWING LOCATION OF
SURFACE TEST WELLS WITH WELL NUMBERS
AND
SURFACE WATER CONTOURS FOR APRIL-1930
SCALE OF MILES
0 1 2 3 4 5
Buena Park
FULLERTON
Cypress
Los Alamitos
Stanton
ANAHEIM
SEAL BEACH
Westminster
Garden Grove
Sunset Beach
Wintersburg
SANTA ANA
HUNTINGTON BEACH
NEWPORT BEACH
PACIFIC OCEAN

ments may be given, Plate XII has been prepared showing the fluctuations of the drainage flow in acre-feet per day, the total amount of rainfall in inches on any particular day of the season, the accumulated increase in flow due to rainfall by five-day periods and the mean percentage of soil moisture above the water table at the nonirrigated site of the Santa Ana station, about midway of the district. The diagram shows the first rain of the season, on January 5, and the first increase in flow over the weir on January 9. In general, the daily flow increased following each rain of one-half inch or more and decreased between heavy rains and also for periods following light rains. The accumulated increase in drainage flow due to rainfall begins at 0.38 acre-foot of flow per day, which was the minimum of the season, and builds up gradually from nothing to 67 acre-feet on June 1. Up to this time rainfall had been so distributed that practically no irrigation was necessary. The resumption of irrigation about June 1, contributed to the moisture already in the soil and caused an increase in flow not due to rainfall and for this reason further observations were discontinued. During the season the total rainfall amounted to 11.1 inches, as measured at the Santa Ana station, which, when computed over the entire 1900 acres drained, amounted to 1757 acre-feet. As but 67 acre-feet, or less than half an inch of rainfall, were measured at Manhole 26 as increase due to rainfall penetration, the balance of 1690 acre-feet of rain which fell upon the drainage area can only be accounted for as soil storage, soil evaporation and transpiration from crops and other vegetation. The penetration of only 67 acre-feet out of a total of 1757 seems a surprisingly small amount to penetrate to a shallow depth through porous soil with a relatively high water table, but it must be remembered that during the entire period of five months only three storms, one in January, one in March and one early in May, occurred and caused immediate penetration to the depth of the drainage system. Each of these storms caused an increase in drainage flow. All other rains were light and the precipitation rapidly evaporated or transpired and did not have time to penetrate deeply into the soil. No doubt a part of the 1690 acre-feet unaccounted for remained in the soil at the time observations were discontinued and eventually reached the water table and should therefore be counted as penetration due to rainfall, and also undoubtedly a part of the total was evaporated or transpired from vegetation, but it is not possible to separate these various amounts. If soil moisture due to rainfall had not been increased by irrigation of crops, further measurements of drainage flow might supply more accurate data regarding total penetration.

In December, prior to any rainfall, and following each of the heavy rains in January, March and May, soil moisture samples were taken at the Santa Ana station to determine soil moisture deficiency and field capacity of the soil at this point. This soil moisture deficiency is not representative of the entire area under consideration as the barren ground at the station is not irrigated and only receives rainfall to replenish the soil moisture, while surrounding cultivated areas receive both rainfall and irrigation. The soil moisture content would, therefore, be much greater throughout the 1900 acres of the district than at the station and the soil moisture deficiency would be less. Computations show that the deficiency at the station on December 9 averaged one inch per foot in the upper five feet of soil and was probably about the same at the end of the dry season early in January. Due to the January storm the soil moisture nearly doubled and rose to about field capacity, increasing very little during the balance of the rainy season. This feature of Plate XII is included merely to show that some of the moisture remained stored in the soil immediately above the water table and that a slow rate of drainage flow supplied by rainfall held in the soil might be expected to continue.

PLATE XII



NOTE:

Total area drained .... 1,900 acres
" rainfall .... 11.1 inches
" " on 1,900 acres .... 1,757 acre-feet
Increase in drainage due to rainfall .... 67 " "
" " soil storage plus evapo-transpiration plus any percolation- 1,690 acre-feet
Soil is Hanford fine sandy loam and Hanford sand.

EFFECT OF RAINFALL PENETRATION ON 1900 ACRES OF NEWHOPE DRAINAGE DISTRICT AS MEASURED AT MANHOLE 26, JANUARY TO JUNE, 1930.

APPENDIX

PRECIPITATION RECORDS

PRECIPITATION RECORDS

The United States Weather Bureau maintains stations scattered throughout the area studied and many other stations have been established in connection with this investigation in districts not immediately covered by the Weather Bureau. Records of rainfall intensity are available from two recording rain gages within the area. Gages were established in connection with all special plots so that records were available at the immediate locations under study.

Records for the 1927–28, 1928–29 and 1929–30 seasons are given for sixteen representative stations in the following tables:

TABLE 1

RAINFALL DATA AT SANTA ANA

U. S. Weather Bureau

1927–28		1928–29		1929–30	
Date of storm	Rainfall in inches	Date of storm	Rainfall in inches	Date of storm	Rainfall in inches
August 28	0.14	October 12–13	0.55	September 18–19	0.53
September 17	.04	November 13	.55	October 2	.04
		November 15	.87	October 14–15	.03
October 26–29	.80				
October 31	.36	December 3–4	1.06	January 6–7	.79
		December 11	.27	January 10–16	4.80
November 1	2.90	December 13–15	1.10	January 18	.13
November 10	.21			January 27	.38
November 13–14	.13	January 16–17	.58	January 29	.18
November 21	.02	January 19–21	.92		
		January 23	.05	February 21–22	.20
December 10–11	1.81			February 24	.33
December 14–15	.69	February 1–4	1.01	February 28–29	.11
December 21–22	.32	February 6–7	.08		
December 26–27	.62	February 18–19	.28	March 3–5	.57
December 29–30	.20			March 14–17	3.63
		March 10–11	1.58	March 19	.21
January 15–17	.29	March 13	.08	March 30–31	.08
February 3–5	2.33	April 4–5	1.00	April 1	.04
		April 19	.09	April 30	.32
March 3–4	.62				
March 6	.86	June 17	.11	May 1	.72
March 24–28	.58			May 3–6	1.44
				May 17	.03
May 8–10	.28				
Totals	13.20		10.18		14.56

TABLE 2

RAINFALL DATA AT TUSTIN

U. S. Weather Bureau

1927-28		1928-29		1929-30	
Date of storm	Rainfall in inches	Date of storm	Rainfall in inches	Date of storm	Rainfall in inches
October 27-28	0.74	October 12-13	0.54	September 18	0.58
October 31	.89				
		November 13-14	1.53	October 2	.05
November 1	2.30				
November 10	.22				
November 13	.04	December 3- 4	1.01	January 6- 7	.79
		December 11	.30	January 9-16	3.85
		December 13-15	.76	January 18	.04
December 10-12	1.26			January 20	.01
December 14-15	.56			January 27-28	.65
December 22	.25	January 16-21	1.62		
December 26-27	.58	January 23	.05		
December 29-30	.24			February 21	.10
				February 23	.23
		February 1- 4	.59	February 27	.11
January 15-16	.31	February 7	.06		
		February 18-19	.45	March 4- 6	.47
				March 14-17	3.63
February 3- 5	1.48			March 19	.08
		March 10-11	.96	March 31	.05
		March 13	.06		
March 3- 5	1.39	March 22-23	.04		
March 24-25	.32			April 1	.26
March 27	.15			April 30	.46
		April 4- 6	1.34		
		April 19	.05		
May 8-10	.32			May 1	.78
				May 3- 5	1.51
		June 17	.11		
Totals	11.05		9.47		13.65

TABLE 3

RAINFALL DATA AT CORONA

U. S. Weather Bureau

1927-28		1928-29		1929-30	
Date of storm	Rainfall in inches	Date of storm	Rainfall in inches	Date of storm	Rainfall in inches
October 25-28	1.17	October 11-12	0.85	September 18	0.65
October 30-31	2.40				
		November 13	.35	January 6- 7	.62
November 9	.35	November 15	.47	January 9-16	3.49
November 13	.14				
		December 3- 4	.82	January 26-27	.75
December 9-11	1.52	December 11	.17		
December 14-15	.20	December 13-15	.92	February 21	.05
December 21	.27			February 23	.55
December 25-27	.75	January 16-17	.41	February 27	.02
December 29-30	.14	January 19-21	1.04		
		January 23	.05	March 5	.40
January 14-15	1.11			March 14-17	2.48
January 22	.01	February 1- 5	.64	March 30-31	.15
		February 7	.16		
February 2- 4	1.96	February 19	.50	April 30	1.45
February 14	.05				
		March 10-11	1.05	May 1	.55
March 2- 3	.45	March 13	.12	May 4- 5	1.18
March 5	.81	March 24	.15	May 16	.12
March 24	.28				
March 27	.05	April 4- 6	1.14		
		April 19-20	.06		
June 8	.01				
Totals	11.67		8.90		12.46

TABLE 4

RAINFALL DATA AT CHINO

American Beet Sugar Company

1927–28		1928–29		1929–30	
Date of storm	Rainfall in inches	Date of storm	Rainfall in inches	Date of storm	Rainfall in inches
October 25–27	0.77	October 11–12	0.53	September 18	0.76
October 30	.75	November 12–14	1.44	January 5–16	5.44
October 31	1.77	December 2–3	1.35	January 19	.03
November 1	3.29	December 10	.21	January 27–28	.52
November 5	.04	December 13–14	1.04	February 20–22	.56
November 8	.47	January 16–21	2.21	February 26	.09
November 13	.15	January 31	.06	March 4	.34
December 9–10	2.14	February 2–4	1.14	March 13–18	4.07
December 14–15	.24	February 7–8	.10	March 31	.11
December 21	.36	February 17–18	.81	April 1	.03
December 25–29	1.03	March 10–11	1.67	April 30	.18
January 15	.17	March 14	.07	May 1–6	2.53
February 2–4	2.49	March 22	.04	May 16–17	.13
March 2–5	1.52	April 4–5	2.39		
March 23–27	.97	April 19	.07		
April 2	.24	June 16	.03		
May 8–9	1.35				
Totals	17.75		13.16		14.79

TABLE 5

RAINFALL DATA AT NAROD

West Ontario Citrus Association, C. W. Fox, Observer

1927–28		1928–29		1929–30	
Date of storm	Rainfall in inches	Date of storm	Rainfall in inches	Date of storm	Rainfall in inches
October 25–28	0.87	October 12–13	0.32	September 18–19	0.64
October 31	.60	November 13–15	1.25	January 6–19	5.81
November 1	1.75	December 3–4	1.04	January 27–28	.56
November 6	.21	December 11–14	1.41	February 21–24	.81
November 10	.38	January 16–21	1.83	February 27	.04
November 14	.16	February 2–6	.91	March 5	.36
December 10–15	2.88	February 19	.69	March 14–18	3.77
December 22	.26	March 10–13	1.59	March 31	.13
December 26–30	1.21	March 19	.04	April 30	.44
January 15–16	.29	March 22–23	.19	May 1–6	3.23
February 3–5	3.10	April 4–5	2.21	May 16–17	.29
March 3–6	1.48	April 20	.09		
March 14	.10	June 17	.33		
March 24–28	1.45				
April 3–4	.54				
May 9–11	1.67				
May 14	.02				
Totals	16.97		11.90		16.08

TABLE 6

RAINFALL DATA AT TWENTY-SECOND STREET, UPLAND

J. R. Johnson, Observer

1927-28		1928-29		1929-30	
Date of storm	Rainfall in inches	Date of storm	Rainfall in inches	Date of storm	Rainfall in inches
October 25-27	0.86	October 11-12	0.72	September 17	0.48
October 31	1.95	November 13-14	1.47	October 14	.03
November 5	.10	December 2	.93	January 5- 7	1.19
November 9	.35	December 10-14	1.89	January 10-16	6.09
November 13	.27	January 15	.86	January 18	.04
December 9-14	2.37	January 19-20	1.35	January 27	.52
December 21	.20	February 1- 7	1.67	February 23	.91
December 26	.81	February 18	.64	February 27	.13
December 29-30	.28	March 9-11	2.55	March 4	.64
January 15-16	.26	March 19	.05	March 14-17	3.75
February 3- 4	3.44	March 22	.24	March 30-31	.10
March 3- 5	1.10	April 3- 5	2.46	April 13	.07
March 13	.14	April 18-19	.17	April 30	1.84
March 24-26	.82	June 16	.21	May 1- 8	2.68
April 2	.88			May 16-17	.27
May 8-10	1.36				
June 18	.12				
Totals	15.31		15.21		18.74

TABLE 7

RAINFALL DATA AT BASELINE AND HERMOSA AVENUES, ALTA LOMA

L. A. Smith, Observer

1927-28		1928-29		1929-30	
Date of storm	Rainfall in inches	Date of storm	Rainfall in inches	Date of storm	Rainfall in inches
October 25-27	0.84	October 12-13	0.89	September 17	0.41
October 31	1.93	November 12-14	1.50	January 5-15	7.15
November 5	.15	December 2	1.17	January 17	.03
November 9	.35	December 10-12	1.57	January 26-27	.53
December 9-10	2.57	January 15-16	.74	February 22-23	.87
December 13-14	.29	January 19-20	1.67	February 27	.16
December 23-29	1.20	February 1- 3	1.27	March 4- 5	.81
January 14-15	.28	February 6	.17	March 14-17	4.64
February 2- 6	3.33	February 18	.74	March 30-31	.38
March 2- 5	1.11	March 9-12	2.14	April 30	1.81
March 13	.25	March 18	.03	May 1- 4	2.31
March 24-27	1.28	March 22	.23	May 16	.17
April 2	.82	April 4- 5	2.11		
May 8-10	1.38	April 8	.02		
		June 16	.20		
Totals	15.78		14.45		19.27

TABLE 8

RAINFALL DATA AT GUASTI

Guasti Wine Company

1927–28		1928–29		1929–30	
Date of storm	Rainfall in inches	Date of storm	Rainfall in inches	Date of storm	Rainfall in inches
October 26–28	0.71	October 11–12	0.50	September 18	1.30
October 31	.40				
		November 12–15	1.11	January 6–7	.46
November 1	1.82			January 10–18	4.55
November 6	.02	December 3	.75	January 27–28	.47
November 10	.32	December 11–15	1.21		
November 13	.12			February 21–23	.65
		January 16–21	2.29		
December 10–14	2.40			March 5	.39
December 27–30	1.32	February 2–4	.84	March 15–18	3.66
		February 19	.73	March 30–31	.84
January 16	.45				
		March 11–13	1.64	April 30	.54
February 3–5	2.85	March 23	.23		
				May 1–5	2.84
March 5–6	.68	April 4–6	2.03	May 15	.11
March 14	.15	April 19	.06		
March 23–27	1.08				
		June 17	.23		
April 3	.50				
May 9–10	1.31				
Totals	14.13		11.62		15.81

TABLE 9

RAINFALL DATA AT WINEVILLE

Charles Stern and Company

1927–28		1928–29		1929–30	
Date of storm	Rainfall in inches	Date of storm	Rainfall in inches	Date of storm	Rainfall in inches
October 26–27	0.62	October 12	0.58	September 16	0.60
October 31	1.90				
		November 11	.45	January 5–6	.28
November 5	.10	November 14	.53	January 10–15	3.88
November 9	[illegible]			January 27	.51
November 13	.07	December 3	.63		
November 20	.02	December 11–14	.94	February 20–22	.58
December 9–10	1.93	January 16	.98	March 4	.76
December 14	.22	January 19–20	1.48	March 14–17	2.91
December 25–26	.65				
December 29	.60	February 1	.64	April 1	.20
		February 4–6	.28	April 20	.08
January 15	.75	February 19	.58		
				May 1–4	3.25
February 2–4	2.12	March 10	1.20		
		March 22	.09		
March 3–5	.90				
March 13	.08	April 4	1.90		
March 24–26	.63	April 18	.09		
April 2	.28				
May 9–10	1.30				
Totals	12.47		10.37		13.05

TABLE 10

RAINFALL DATA AT RIVERSIDE

U. S. Weather Bureau

1927–28		1928–29		1929–30	
Date of storm	Rainfall in inches	Date of storm	Rainfall in inches	Date of storm	Rainfall in inches
October 25–28	1.25	October 11–12	0.56	September 17–18	0.63
October 30	2.27				
		November 12	.37	January 7– 8	.41
November 9	.20	November 14	.41	January 10–12	3.53
November 12	.02			January 18	.09
		December 3	.48	January 27–28	.62
December 10–11	1.13	December 11	.15		
December 14	.06	December 13–14	.84	February 21	.15
December 21	.31			February 23–24	.44
December 25–27	.64	January 15–16	.45	February 27	.05
December 29	.20	January 18–20	.94		
				March 5	.54
January 15–16	.77	February 1– 2	.19	March 15–17	2.52
		February 4– 7	.34	March 31	.21
February 3– 4	2.21	February 19	.30		
				April 1	.26
March 3– 6	.62	March 10–11	.52	April 30	.41
March 14	.01	March 13	.30		
March 24	.20	March 21–22	.06	May 1– 5	3.06
March 26–27	.06	March 24	.04	May 9	.08
				May 17	.07
April 3	.10	April 4– 5	1.30		
		April 18–20	.16		
May 7– 9	.94				
		June 16	.03		
Totals	10.99		7.44		13.07

TABLE 11

RAINFALL DATA AT ETIWANDA

W. F. Barnes, Observer

1927–28		1928–29		1929–30	
Date of storm	Rainfall in inches	Date of storm	Rainfall in inches	Date of storm	Rainfall in inches
October 25–27	0.71	October 11–12	0.60	September 18	0.49
October 31	2.28				
		November 12–14	1.34	January 5–16	7.61
November 10	.50			January 27	.56
November 13	.33	December 3– 4	1.52		
		December 10	.48	February 20–23	.96
December 10–11	2.10	December 13	1.10	February 27	.26
December 14	.36				
December 21	.26	January 15–16	.73	March 4	.89
December 25–29	1.11	January 19–21	2.01	March 14–17	4.40
				March 31	.46
January 15–17	.56	February 1– 6	1.85		
		February 18	1.10	April 30	1.90
February 3– 4	2.49				
		March 10	2.15	May 1– 8	2.60
March 3– 6	.78	March 18	.07	May 16–17	.30
March 13	.15	March 22	.25		
March 24–27	1.54				
		April 3– 5	2.31		
April 3	.88	April 19	.15		
April 24	.03				
		June 16	.22		
May 9–12	1.10				
Totals	15.18		15.88		20.43

TABLE 12

RAINFALL DATA AT SAN BERNARDINO

U. S. Weather Bureau

1927–28		1928–29		1929–30	
Date of storm	Rainfall in inches	Date of storm	Rainfall in inches	Date of storm	Rainfall in inches
October 25–29	1.67	October 11–12	0.82	September 5	0.01
October 31	1.60			September 18	.52
		November 13–15	1.10		
November 1	.66			October 28	.05
November 6	.04	December 3	.65		
November 10	.23	December 11	.43	January 5	.20
November 13–14	.16	December 13–14	.91	January 7	.25
				January 9–16	4.06
December 10–12	1.61	January 16–21	2.28	January 18	.10
December 14	.10			January 27	.51
December 21–22	.48	February 1– 2	.59		
December 25–27	.57	February 4	.26	February 20	.30
December 28–29	.63	February 6– 7	.30	February 22–23	.80
		February 18–19	.74	February 26	.05
January 15–16	.74			February 28	.01
		March 9–10	1.23		
February 3– 5	2.65	March 13	.02	March 5– 6	.42
		March 19	.01	March 14–17	2.56
March 2– 6	.77	March 23–24	.32	March 30–31	.82
March 13–14	.16	March 30	.02		
March 24–25	.34			April 13	.01
March 27	.03	April 4– 6	2.15	April 15	.02
		April 18–19	.26	April 30	1.05
April 2	.51				
		June 16	.12	May 1– 5	2.21
May 8–10	1.04			May 7	.01
May 12	.02			May 16–17	.10
May 14	.03				
May 17	.01				
Totals	14.05		12.21		14.06

TABLE 13

RAINFALL DATA AT REDLANDS

U. S. Weather Bureau

1927–28		1928–29		1929–30	
Date of storm	Rainfall in inches	Date of storm	Rainfall in inches	Date of storm	Rainfall in inches
July 20	0.05	October 3	0.03	August 4	0.10
October 25–28	1.60	October 12	.85	September 18	.56
October 30	.81	November 13–15	1.12	September 21	.03
November 1	1.24	December 3	.66	January 5–16	4.75
November 10	.15	December 11	.26	January 18	.10
November 13	.04	December 13–14	.82	January 27	.72
December 10–11	1.30	January 16	.50	February 20	.05
December 14	.10	January 19–21	1.24	February 23	.48
December 21	.60	February 1– 2	.60	February 27	.06
December 25–29	1.19	February 4	.19	March 5	.52
January 15–16	.33	February 6– 7	.27	March 14–19	3.27
February 3– 4	2.13	February 18–19	.57	March 31	.64
March 3– 6	.77	March 10–11	.71	April 1	.56
March 24–25	.34	March 13	.11	April 30	.42
March 27	.11	March 19	.05	May 1– 7	4.01
April 3	.13	March 22–24	.39	May 9	.02
May 8–10	1.52	April 4– 6	2.16	May 17	.10
May 14–15	.05	April 18–19	.32		
May 17	.02	June 16	.04		
June 19	.04				
Totals	12.52		10.89		16.39

TABLE 14

RAINFALL DATA AT MOUTH OF SAN ANTONIO CANYON

U. S. Weather Bureau

1927–28		1928–29		1929–30	
Date of storm	Rainfall in inches	Date of storm	Rainfall in inches	Date of storm	Rainfall in inches
October 25–28	0.95	November 13–15	1.63	September 18	0.50
October 31	.49				
		December 10–12	2.51	January 5	.48
November 1	1.29	December 14–15	.06	January 7	.81
November 6	.07			January 9–12	4.45
November 10	.48	January 16–17	1.29	January 14–17	1.81
November 12–13	.27	January 19–20	1.40	January 27	.58
December 10–12	2.51	February 1– 4	2.02	February 20	.01
December 15–16	.06	February 6	.49	February 21–22	1.01
December 23	.25	February 18	.81	February 27–28	.29
December 27–28	.74				
December 30	.08	March 9–10	3.38	March 4– 5	1.41
		March 13	.04	March 14–17	4.44
January 15–17	.62	March 22–23	.17	March 30–31	.40
February 3– 5	3.94	April 3– 5	3.19	April 13	.07
		April 18–19	.12	April 29–30	1.97
March 3– 4	.43				
March 6	.91	June 16	.17	May 1– 8	4.38
March 14–18	.43			May 16–17	.37
April 3– 4	.86				
May 9–10	1.19				
May 15	.01				
June 18–19	.05				
Totals	15.63		17.28		22.98

TABLE 15
RAINFALL DATA AT LYTLE CREEK
U. S. Weather Bureau

1927-28		1928-29		1929-30	
Date of storm	Rainfall in inches	Date of storm	Rainfall in inches	Date of storm	Rainfall in inches
July 26	0.12	October 11-12	1.20	July 18	0.08
				July 31	.09
October 25-27	.92	November 13-15	1.50		
October 31	2.41			September 18	.50
		December 3- 4	3.26		
November 6	.32	December 10	.88	January 5- 6	1.33
November 10	.90	December 12-13	2.08	January 9-12	3.03
November 13	.56			January 14-16	5.66
		January 16	1.24	January 18	.10
December 10-11	2.86	January 18-21	4.13	January 27	.78
December 14	.24				
December 21	.44	February 1- 2	2.53	February 20-23	2.56
December 25-27	.66	February 4	.92		
December 29-30	.57	February 6	1.36	March 4- 5	1.36
		February 18-19	1.29	March 14-17	5.47
January 15-17	.70			March 31	.35
		March 9-10	4.70		
February 3- 4	4.18	March 22-23	.89	April 30	2.58
March 3	.51	April 4- 6	4.29	May 1- 5	3.39
March 5- 6	1.56	April 9	.07	May 7	.41
March 13	.33	April 19	.91	May 15-17	.20
March 24-27	2.09				
		June 16	.52		
April 3	2.45				
April 24	.21				
May 8-9	1.34				
Totals	23.37		31.77		27.89

TABLE 16
RAINFALL DATA AT DEVORE RANCH
U. S. Weather Bureau

1927-28		1928-29		1929-30	
Date of storm	Rainfall in inches	Date of storm	Rainfall in inches	Date of storm	Rainfall in inches
October 26-28	1.27	October 12-13	1.14	September 18	0.96
October 31	.42				
		November 13-14	1.43	January 6- 7	1.24
November 1	1.52			January 10	3.00
November 6	.18	December 3- 4	2.94	January 13-16	6.18
November 10	.92	December 12-14	3.20	January 27-28	.82
November 14	.83				
		January 16-17	1.07	February 22-24	2.29
December 10-11	2.49	January 19-21	3.96	February 26	.20
December 14	.30			February 28	.32
December 22	.45	February 2	3.06		
December 26-30	1.27	February 4	.86	March 5	1.28
		February 6- 7	2.06	March 15-16	5.26
January 15-17	.86	February 18-19	.96	March 31	.92
February 3- 5	4.11	March 10-11	5.52	April 1	.27
		March 18	.20	April 30	1.40
March 2- 3	.52	March 23-25	.80		
March 6	1.21			May 1- 5	5.05
March 14	.52	April 4- 6	3.16		
March 24-28	2.40	April 19-20	.72		
April 3- 4	2.19	June 16	.28		
May 9-10	1.18				
Totals	22.64		31.36		29.19

PUBLICATIONS

DIVISION OF WATER RESOURCES

PUBLICATIONS OF THE

DIVISION OF WATER RESOURCES

DEPARTMENT OF PUBLIC WORKS

STATE OF CALIFORNIA

When the Department of Public Works was created in July, 1921, the State Water Commission was succeeded by the Division of Water Rights, and the Department of Engineering was succeeded by the Division of Engineering and Irrigation in all duties except those pertaining to State Architect. Both the Division of Water Rights and the Division of Engineering and Irrigation functioned until August, 1929, when they were consolidated to form the Division of Water Resources.

STATE WATER COMMISSION

First Report, State Water Commission, March 24 to November 1, 1912.
Second Report, State Water Commission, November 1, 1912, to April 1, 1914.
*Biennial Report, State Water Commission, March 1, 1915, to December 1, 1916.
Biennial Report, State Water Commission, December 1, 1916, to September 1, 1918.
Biennial Report, State Water Commission, September 1, 1918, to September 1, 1920.

DIVISION OF WATER RIGHTS

*Bulletin No. 1—Hydrographic Investigation of San Joaquin River, 1920–1923.
*Bulletin No. 2—Kings River Investigation, Water Master's Reports, 1918–1923.
*Bulletin No. 3—Proceedings First Sacramento-San Joaquin River Problems Conference, 1924.
*Bulletin No. 4—Proceedings Second Sacramento-San Joaquin River Problems Conference, and Water Supervisor's Report, 1924.
*Bulletin No. 5—San Gabriel Investigation—Basic Data, 1923–1926.
Bulletin No. 6—San Gabriel Investigation—Basic Data, 1926–1928.
Bulletin No. 7—San Gabriel Investigation—Analysis and Conclusions, 1929.
*Biennial Report, Division of Water Rights, 1920–1922.
*Biennial Report, Division of Water Rights, 1922–1924.
Biennial Report, Division of Water Rights, 1924–1926.
Biennial Report, Division of Water Rights, 1926–1928.

DEPARTMENT OF ENGINEERING

*Bulletin No. 1—Cooperative Irrigation Investigations in California, 1912–1914.
*Bulletin No. 2—Irrigation Districts in California, 1887–1915.
Bulletin No. 3—Investigations of Economic Duty of Water for Alfalfa in Sacramento Valley, California, 1915.
*Bulletin No. 4—Preliminary Report on Conservation and Control of Flood Waters in Coachella Valley, California, 1917.
*Bulletin No. 5—Report on the Utilization of Mojave River for Irrigation in Victor Valley, California, 1918.
*Bulletin No. 6—California Irrigation District Laws, 1919 (now obsolete).
Bulletin No. 7—Use of water from Kings River, California, 1918.
*Bulletin No. 8—Flood Problems of the Calaveras River, 1919.
Bulletin No. 9—Water Resources of Kern River and Adjacent Streams and Their Utilization, 1920.
*Biennial Report, Department of Engineering, 1907–1908.
*Biennial Report, Department of Engineering, 1908–1910.
*Biennial Report, Department of Engineering, 1910–1912.
*Biennial Report, Department of Engineering, 1912–1914.
*Biennial Report, Department of Engineering, 1914–1916.
*Biennial Report, Department of Engineering, 1916–1918.
*Biennial Report, Department of Engineering, 1918–1920.

*Reports and Bulletins out of print. These may be borrowed by your local library from the California State Library at Sacramento, California.

DIVISION OF WATER RESOURCES

Including Reports of the Former Division of Engineering and Irrigation

*Bulletin No. 1—California Irrigation District Laws, 1921 (now obsolete).
*Bulletin No. 2—Formation of Irrigation Districts, Issuance of Bonds, etc., 1922.
Bulletin No. 3—Water Resources of Tulare County and Their Utilization, 1922.
Bulletin No. 4—Water Resources of California, 1923.
Bulletin No. 5—Flow in California Streams, 1923.
Bulletin No. 6—Irrigation Requirements of California Lands, 1923.
*Bulletin No. 7—California Irrigation District Laws, 1923 (now obsolete).
*Bulletin No. 8—Cost of Water to Irrigators in California, 1925.
Bulletin No. 9—Supplemental Report on Water Resources of California, 1925.
*Bulletin No. 10—California Irrigation District Laws, 1925 (now obsolete).
Bulletin No. 11—Ground Water Resources of Southern San Joaquin Valley, 1927.
Bulletin No. 12—Summary Report on the Water Resources of California and a Coordinated Plan for Their Development, 1927.
Bulletin No. 13—The Development of the Upper Sacramento River, containing U. S. R. S. Cooperative Report on Iron Canyon Project, 1927.
Bulletin No. 14—The Control of Floods by Reservoirs, 1928.
*Bulletin No. 18—California Irrigation District Laws, 1927 (now obsolete).
Bulletin No. 18—California Irrigation District Laws, 1929 Revision.
Bulletin No. 19—Santa Ana Investigation, Flood Control and Conservation (with packet of maps), 1928.
Bulletin No. 20—Kennett Reservoir Development, an Analysis of Methods and Extent of Financing by Electric Power Revenue, 1929.
Bulletin No. 21—Irrigation Districts in California, 1929.
Bulletin No. 21-A—Report on Irrigation Districts in California for the Year 1929, 1930.
Bulletin No. 21-B—Report on Irrigation Districts in California for the year 1930, 1931.
Bulletin No. 22—Report on Salt Water Barrier (two volumes), 1929.
Bulletin No. 23—Report of Sacramento-San Joaquin Water Supervisor, 1924–1928.
Bulletin No. 24—A Proposed Major Development on American River, 1929.
Bulletin No. 25—Report to Legislature of 1931 on State Water Plan, 1930.
Bulletin No. 28-A—Industrial Survey of Upper San Francisco Bay Area, 1930.
Bulletin No. 31—Santa Ana River Basin, 1930.
Bulletin No. 32—South Coastal Basin, a Cooperative Symposium, 1930.
Bulletin No. 33—Rainfall Penetration and Consumptive Use of Water in Santa Ana Valley and Coastal Plain.
Bulletin No. 34—Permissible Annual Charges for Irrigation Water in Upper San Joaquin Valley, 1930.
Bulletin No. 35—Permissible Economic Rate of Irrigation Development in California, 1930.
Bulletin No. 36—Cost of Irrigation Water in California, 1930.
Biennial Report, Division of Engineering and Irrigation, 1920–1922.
Biennial Report, Division of Engineering and Irrigation, 1922–1924.
Biennial Report, Division of Engineering and Irrigation, 1924–1926.

COOPERATIVE AND MISCELLANEOUS REPORTS

*Report of the Conservation Commission of California, 1912.
*Irrigation Resources of California and Their Utilization (Bul. 254, Office of Exp. U. S. D. A.) 1913.
*Report, State Water Problems Conference, November 25, 1916.
*Report on Pit River Basin, April, 1915.
*Report on Lower Pit River Project, July, 1915.
*Report on Iron Canyon Project, 1914.
*Report on Iron Canyon Project, California, May, 1920.
*Sacramento Flood Control Project (Revised Plans), 1925.
Report of Commission Appointed to Investigate Causes Leading to the Failure of St. Francis Dam, 1928.
Report of the Joint Committee of the Senate and Assembly Dealing With the Water Problems of the State, 1929.
Report of the California Joint Federal-State Water Resources Commission, 1930.
Conclusions and Recommendations of the Report of the California Irrigation and Reclamation Financing and Refinancing Commission, 1930.
Report of the Joint Committee of the Senate and Assembly Dealing with the Water Problems of the State, 1931.

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*Reports and Bulletins out of print. These may be borrowed by your local library from the California State Library at Sacramento, California.

PAMPHLETS

Rules and Regulations Governing the Supervision of Dams in California, 1929.
Water Commission Act with Latest Amendments Thereto, 1929.
Rules and Regulations Governing the Appropriation of Water in California, 1930.
Rules and Regulations Governing the Determination of Rights to Use of Water in Accordance with the Water Commission Act, 1925.
Tables of Discharge for Parshall Measuring Flumes, 1928.
General Plans, Specifications and Bills of Material for Six and Nine Inch Parshall Measuring Flumes, 1930.

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